McGraw-Hill Encyclopedia of Science and Technology 10

McGraw-Hill Encyclopedia

McGRAW HILL BOOK COMPANY INC

NEW YORK CHICAGO SAN FRANCISCO DALLAS TORONTO LONDON

of Science and Technology

AN INTERNATIONAL REFERENCE WORK

IN FIFTEEN VOLUMES INCLUDING AN INDEX

VOLUME 10 PER PROG

(LEFT) Photom c og aph of copper sulphate a d calc m carbonate crystals (L C Massop t) (RIGHT) A m croscop cal e plos on of chem cal forces (photograph by R V hn ac)

M GRAW HILL ENCYCLOPEDIA OF SCIENCE AND TECHNOLOGY

Library of Congress Catalog Card Number 60 11000

Suggestions to the Readers

The ba pl f th Ency l p d e plain d h re i o d to fa litat t

Th bje t natt f th r us di c pl ne or b ch s f nce d t hn lopy i rean ed s i m t all ge l t le p ov dc a b ad r y f th f ld d mb r of ep ate rt cle alph bet call a an d c e t m m ubdi ons n i m j fi a pe t

Cr ef n e ou le th e de f om th gen l rt f t tf oth r art l s nt wh h th ubje t uld d l d nd tr m th to rt le on mo h ht pe l zed ph f th ubj ct The c o r f —th e ab ut 50 000 of them—a p ted mall c p t l l tt that th e n b a ls e m l B rr f the cro efe n es l a f l h way f om ELECTRIC L ENGINEER t th l E ECTRO ICS and V LUM TUBE to ELE TR t TIO I CULM O ELECTRON EM S ION O f ll oth l n f e r f n es the l ld be l d t ELECTRIC PO ER Y TEMS, TR N ION L NES ELECTROMA ETIC A VE d

In g r f h t l been th defi it f th titl th t t tes t ye d r t l lly nl tl nt fi t h l gi al n d d M t f th t l ft th t t m nt n t gl mpl n l d t iled on id t A d th u l t p ceed ls as f h s i l n t n d eq m t di tat

Th l l l l m 15 l ld be ult d t lo t tl d n f t p s d n th En l ped t t n t g n p r te nt

f fh l m l d d t th pl t d m l k ml ll tted p r t ticl M f ch m mm f m l g nd p e el th n f th de t el o pa t t l l t wri nt fi r e mmo n m

Th ljcm l t l l t i l d l t ll n El t —e ntai pr d c l t ted l ng l trr itt s capable of doin o a for in ta ce el ctr g ner tor el ctr m tcr l ct c w r n El ctr cal—elat d t p rta n to t r a ociated ith electr c ty b t not hav ng t pr pert ch ra te t cs a f r ample l t cal code el t s l en ne r

Wo l ed a mil ar wl e p itle g ven the in lar t pe n t a c n t nt lpl abet c r an em nt Title a e alpl abeti c l l s c l an l not by letter for e ample

Earth sciences
Earth tides
Earthmover
Earthquake

A w rd ed a n prec de the me wo d u ed dje t all tl u

Mercury (element)
Mercury (planet)
Mercury battery

Circuit electronic
Circuit breaker

Hyphened t rm e lph betiz d a l wo d fo mple

Animal virus
Animal feed composition

Mo t f th lo r a t l o ta n l bli r phie t n u t l o r e of f tle inf rmati f r ld t l bibl rr pl al tat on tl r ade h uld ef r t l t d t l (as ind cated b th c o s efe in tl a t l) Bbl pl s e pla ed at the nd of art le o rr t m at tl nd f m j t s n l ng rt l

A l t f m tal nd m of th nt but to the En l p i s to b found n Volume 15 Tl l t w h pe m t ju k ilent fi t f nt b t u l aft a rt le Imm l at ly f llowin th l t c nd l t of vel ped nt l utor w th tl ffil at a l th t tl f n le a h l w tt f th En y l ped a

McGraw-Hill Encyclopedia of Science and Technology

Peracarida

A up r rder of the cla Cru t cea ubclas Mala tra a. Comm n xample of th ord r are the po m hr mp quat c ow b g and desw m m r The l e a r d lud the rd s Amphi pod C ma e I op da My dac a Spelae gri fl ac a d Ta d cea The e orders sh re a num b f hara ters the m t notable b ng th t the y ung d elop within th rac c mar up m wh ch th y le e at a late stag f de l pment Th ma up um i form d by fr m l 7 memb anous oste g te wh ch e t nd i w rd f om th c xopod t f the th r l gs Th egg d el p ng y g l e f ee n th p e betwee the entral urf e f the th x nd the rl p ng t g t s Meml s of th d Therm ba nacea h a d s l mar p um f med by the p t t o p rt f the r p eq tly they are ex lud d fr m th I r a d by m a th r ties

Oth f atures wh h d ting h th Per arid I m th g p f M l tr c a e the f ll w g Th p t p d te of the e d ant nna u ally n t f th e gment The tho c leg e fi ed b t e th fifth and xth gm t The *h art* i g n all lo g te e t d ng th u h th g t p t f th tho a r g n the *i op d* tt m v xt d t I nt ly n th l d m n wh e esp at y h nge oe ur Spe mat zo ll fil f rm nt a t t th i ph r l r es f r f m th Eu d a d H pl d

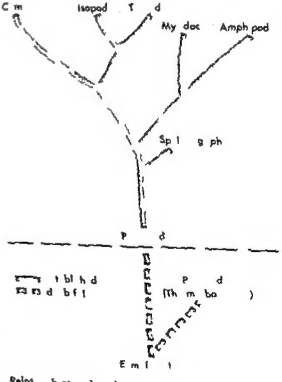
Morphology A n th r Mal o t a the th x t f ight m t the fir t f wh ch f ed w th th h d A r p pre nt n ll d b t tl Amph pod a d Isop d but it d ot ales e with m than f ur th ra t s m t f ll e egm t n the Spelaeo f ha tw n th Tan id ce n t fo th M d d th f r the C ma

Ep pod tes a p t n the ma ll p ds of the rd h g a p r d th m m nt ke p t f w i fl g l g the i s rfa f th a ap In th mysid ubord My da the nn r f e h ghly a l nd ga eou e h ng takes pl th i gh it M mb f the my d h d I ph g tt da h w ha pi pod I g ll n th th l gs nd i the m th m ll pedal p pod te f rm a ompl g ll Th sopod ha fl tt ned p pod t n the m ll ped b t the app nt! n t b a h l I th f m les f some g up f pod a l pp t f th ena pod t of th m x ll ped p ject b k w d d t g th with th p pod te nd an x pan i n of the b ipodite forms a lamellar plat \ br to y m sements c f the ma ill ped ncluding thi pl t end a c rr nt f water through the m r upi m whi h aerates the developing embry

Re pi ati n n i p ds takes place thro gl the ur fa e f the pl pod In the amph pods ga eous ex ha ge ce s in the ep podi l gill attached to the i ner rfac s of the th racic leg There is no p podite n tl e max lliped

Re pi at y epip d tes a e f und only in the Sp l og iphacea wh e they are pre ent n the f fth to e enth thorac le$_g$s

The thor x i f llowed l y an abdomen of six segments b ar ng up t fi e pa rs of *biramo is s m m ng legs or ple pods* On the l rmi l gment the e s a pair f urop d whi h t geth r with the tel on fo m a t il f n Th u leop ds ar ab ent in all female and s me male c mac ans In female t na dacean they m y be redu ed r abs nt and th y may be udim ntary in female my ds In mph pod the bd minal appendage re harply d ded into tw g o p the three anter r p i s a e turned f rw d and natat ry while the la t thre all e lled ur p l a e tur ed backwa d A



Relat h ps w th th P d

mentioned before some or all of the pleopods in the isopods function as gills and the surfaces may be plicated to increase the respiratory area One of the anterior pairs of pleopods or in the suborder Valvifera the uropods may be modified into an operculum protecting the delicate respiratory pleopods In some mysids and isopods one or two pairs of pleopods are modified in the males to assist in the transfer of sperm to the female

Relationships among Peracarida The Peracarida can be divided into two groups The probable relationships are shown in the illustration Some of the characters on which these relationships are based are presented

The embryo in the Amphipoda is bent ventrad and lies with the dorsal side toward the outside of the egg The position is reversed in the cumaceans tanaids isopods and mysids Cumaceans isopods and perhaps tanaids leave the egg with the eighth thoracic leg absent Mysids and amphipods hatch with all their appendages

Between broods females of cumaceans and some isopods lose their oostegites In mysids and amphipods the oostegites are retained during this period

The lophogastrid mysids have antennal and maxillary nephridia the latter being small Cumaceans tanaids and isopods have maxillary nephridia while amphipods and the mysids other than lophogastrids have antennal nephridia

Other criteria mainly details of the anatomy of the digestive tract have been treated by R Siewing [T E B]

Bibliography W Kukenthal and T Krumbach (eds) *Handbuch der Zoologie* vol 3 no 6 1927 R Lankester (ed) *A Treatise on Zoology* pt VII fasc 3 1909 R Siewing Besteht eine engere Verwandschaft zwischen Isopoden und Amphipoden? *Zool Anz* 47(7–8) 166–180 1951 R Siewing Untersuchungen zur Morphologie der Malacostraca (Crustacea) *Zool Jahrb Abt Anat u Ontog Tiere* 75 39–176 1956

Perception

The process by which an individual is acquainted with his immediate surroundings It can be defined by such behavior as looking listening and touching or otherwise reacting with discrimination to the objects and events of the environment For the human animal it can also be defined in terms of precise verbal activities such as naming describing comparing and distinguishing objects Finally inasmuch as it seems to be possible for the human observer to note the process of perception as it occurs in himself it can be defined as awareness of the external world or consciousness or experience of it

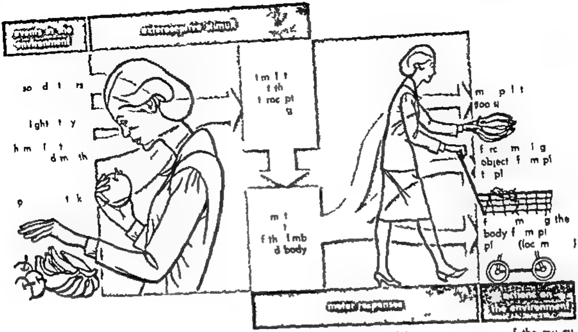
However defined perceiving is distinguished from remembering which refers to past events from expecting which refers to future events and from imagining which refers to absent or nonexistent states of affairs But in no case can these distinctions be sharply drawn since the present environment in time and space cannot in fact be divided from either the past the future or the distant environment by any sharp line of demarcation Now is not a single instant of time and here is not a single point of space There is a considerable span of perception in time and a considerable range of perception in space Hence perceiving is not clearly separable from knowing in the general sense of the term This discussion is concerned primarily with perception and only secondarily with apprehension

Acquaintance with the environment is obviously dependent on the senses and therefore the study of the perceptual process is inseparable from the study of the sensory processes (*see* SENSATION) As John Locke put it knowledge comes through the senses and from no other source To believe on the contrary in a mysterious process of intuition or in the efficacy of innate ideas or the power of pure reason has never been popular in Western scientific thought

Specifically this means that perceiving depends on the stimulating of receptive mechanisms such as the eye ear or the skin of an individual by energy in the surrounding environment The kinds of energy to which human beings and animals are sensitive are light heat sound chemical energy mechanical force and gravitational force The energy at a sense organ is called the proximal stimulus the source of light sound odor or mechanical pressure is sometimes called the distal or distant stimulus Usually a distal object or event causes the stimulation of several sense organs at the same time and the contemporary modes of stimulation combine to form a single percept A fire is seen heard smelled and its warmth is felt Usually there is more than enough sensory input to yield a percept But when stimulation of one channel fails for any reason perception depends on those remaining and when stimulation of all channels is eliminated perception ceases

Perception thus depends on events at several successive stages the external situation the energy at the receptors the excitation of the receptors the transmission of neural impulses and complex processes in the brain which make possible both perception and behavior If the chain of events is interrupted at any stage the whole channel stops functioning For example vision will fail if (1) there is nothing to see as with an observer floating in empty space (2) there is no illumination as in pitch darkness (3) the light entering an eye is diffused as with spectacles of ground glass (4) the light entering an eye is interrupted as when the eyelids are closed (5) the eye becomes opaque as with cataract (6) the retina is damaged as in glaucoma (7) the optic nerve is cut or (8) the area of the brain to which it leads is destroyed In any of these cases a man will be effectively blinded *See* VISION

As an exploratory process Perceiving differs from sensing as this term is traditionally used in being an active rather than a passive or merely receptive process Introspectively it is characterized



Th l c l tm l p f m l Stm l p o- nd th p od ed by g o po e of the mu cu d d by r p l ft t f c t b th th f t p od d by plo t ry p f e se g

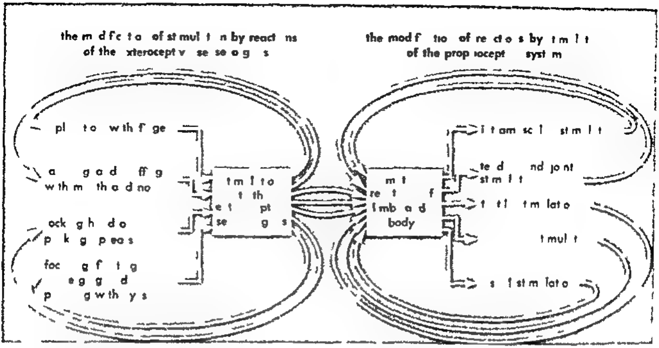
ed by what s c ll d s lecti e att nt o o n ffo t afte cl a n a h f rm ant g Be ha rally t lw vs v l at th ery l ast, me kind of adju tme t f the ense o g n

F exampl the pr mary r a ti of the human ey t l ght s th fo u ng of th m ge a c mmo- d t o d the nt t g f the fo e on s e es t e d t il expl at ry fix t o Co t t t mulati normally m l mo em nts f the finge t pro- d e p e r n the k n a ti e pro of t u h ng ath r than a pa t ne of be g tou h d T ste d mell ol e a ing a d niffing E n h a ng l ad t h l te ng t p n es as ass st e n l l n g th rd ng b t Th ch t of ev t n a s ory ch nn l then m l a cir l t th h d thereby st m l t l ds to d ju tm nt p d ng m st mul ti There is p ese t b alogy with elect on c sy tem a feedb k loop in every s ns ry sy tem It seem t e the f nct o of mak ng st m l ti n optim l f pe pt The f cu g of the eti al image reg te detail nd the expl ation of the ambie t l ght reg te a whole set f det l F using and ploratio nec ary fo the ac rate percep- n of o e s s rrou d g The p rce r se hes th array f l ght for mea ngful shapes in the o ll p tt rn

Th tim l f an t e e e o ga s d s- t g hed f m th st m l f r recept r ll f th rg n t f patt rn of n gy and e q es of p tt rn Thes a e the elev t timuli f p epti A llect n f cell th r t na d th ochl a e s ti e t the mple bles f fr q e y a d i t ity The r t a is spec li d f r l ght e gy d th ochle f r so d e e gy B t a f th body the y a d th ars r n iti e to p tterns and trans t ons of freq ency a d intens ty i the a r y of light and n the flux of ou d The mo a c f eceptors in the r tina or the ochle an be e cited i en rmo sly c mpl c ted omb nat ons of dja ent and su ce s ve o der Ac rdi gly the eye and the ear s total systems can espo d t the compl x ariables of pattern and eq e ce i the total timulat ng s tuat n

Consid r ng the acts f look ng l st ning feel ing mell ng nd t st ng as s le ti re p ns s it become ident that th re is always mo p otent al st m lu f rm ti n at the urface f nd idu l at any gi en t me th n he c n pos il ly handle M reo r th re a lways m re pot nt al se- q nce f timulat n than the ne or th few he n hoo e to xpl The en ironm t t be re- g rd d s n xha t ble re er oir of potent al timul Th pe eptual pr e s is one of el cting and p r uing tho e wh ch ar impo tant for th ind v du l P rc ption i m ti ated by i te e t that by gil nt cur ity Its aim is the egistrat n and cl ifi ation of objecti e f ts But, ob ious l d ffere t facts are imp rtant for different ind id uals or fo the s me nd du l at d ffe ent t mes Pe cept on dep ds on what the p rcei er i in tere t d

As a process of monitoring behavior Al tho gh pe ei g tradit nally defi d as ac qu t ng the nd d al w th h s en i nme t t q a t the indi d al w th hi wn act on It ha i the wo d of C. S Sh ringt n th f m u t th t y p ych l g t p prioc pt fun t o a well a an e t rocepti e f nct n when r the d idu l gag d n any kind f be- b y nd m re ont mplation of th nvi on me t. In dditi t th e so y ha n ls so fa



The feedback loops for exploring or enhancing external stimulation and those for controlling behavior. The angular lines represent physical actions; the curved lines represent neural actions.

considered there is the kinesthetic. This is served by various kinds of receptors in the muscles, tendons, and joints and by still others in the inner ear (see KINESTHETIC SENSATION). Conceived broadly, the sensitivity of an individual to the behavior in which he is engaged is much more than a single sense. It includes all stimulation produced by responses, and this extends at least to touch and vision. When handling things or walking about, a man feels his activity by the changing pressures on the skin, and he sees it by the changing patterns at the eye; he even hears it by the noises at the ear unless he is careful to be silent during manipulation or locomotion. There are many channels for this "feedback" from response, some of the stimuli being inside the skin of the organism and some being outside, but all of these circular loops have a common function: they keep the individual informed about the outcome of his muscular movements and about the progress of his action. They also serve to guide or control behavior inasmuch as they define the terminal act of a course of action and indicate the degree to which it has not yet been reached (see CYBERNETICS).

The kind of perception which is produced by action is not as familiar as the kind which is produced by the environment as such. It is harder to investigate, and it is only beginning to be understood. But obviously the two kinds must be interlocked. In locomotion, for example, an animal needs to perceive both that he is moving through his environment and also where he is going and how close he is to his goal. For this he must be able to perceive the layout of his environment. The visual control of locomotion, therefore, is not separable from the visual perception of space. A walking man has to be able to feel and see himself moving and at the same time to feel and see the motionless ground beneath his feet. This necessity raises the question of the so-called "constancy" of environmental perception, which will be discussed later.

Relationship to the motivating of behavior. If the perceptual process acquaints the individual with his own actions as well as with the environment, the question may be asked whether it also informs him of his own inner needs and of those outer objects which afford satisfactions of his needs. Does perceiving motivate action as well as being itself a kind of motivated act? Such questions raise difficult theoretical issues. To some extent an animal or a man can discriminate among or perceive his own biological needs (see HUNGER; PAIN, DEEP; THIRST). Likewise an animal or a man can identify food, mate, shelter, and other objects of his environment beneficial or noxious with considerable success. But the relation of these disparate facts to the motivation of behavior is a controversial question (see MOTIVATION). A man who comes across a rattlesnake in his path perceives and feels and acts all at the same time, and the psychologist's arbitrary separation of these processes fails.

Introspectively, percepts seem to have a subjective reference as well as an objective reference, but some have much more than others. In a painful experience the subjective pain dominates, whereas in a visual experience the object dominates. But even in visual perception there is the implicit sense of "here," and in auditory perception there is the awareness of "now." However objectively oriented one's experience of the world may be, there lurk in the background a variety of tensions, feelings, emotions, the image of the body, and the consciousness of self. Philosophers and psychologists have long recognized the importance of these subjective facts. But they are not easily put to experimental test and so are given little emphasis in scientific psychology.

Guessing supposing or surmising Con ider t n has been m de up m this po nt f the kind f perc pt n character zed by feel g of ertainty and a testable depe d e n the timulat on of se e rg ns The a e many kinds of apprehen n however wh ch re le rt in and l ob i ou ly d pendent on stimulation They are not ord ar ly called p re vi g but gu g or pp ng urm ng The e s a great differe ce between ob rv t on a d inferen e but t the ame t m *there i often suppo ed to be an element of infer en e i ll pe cept o e en the mple t kind* This ari es f om two th oretical sumpt ons fi st that *ly the so-called ensati s are c rt in and clea and seco d that they are m anıngle s O th s as umpt on some th e ry of a per eptu l p ocess* hi h ppl me t the ensati s s nece ry *Co eq ently th re h s b en a gr at inte est in the* r ou type f nc rta n pp h nsi n w th the hope that they w ll reve l the nature f the s te n l e t buti t en ry data

Many k ds of gue ng and it ari ts may oc cur but they ar n t e ly d sti gu hed by intro pect n Th re re exp r me tal meth ds how eve for p odu g some f them and the e may be l ted as g v g p t al cla s f cat n

C el s b e rati o d t d d attent n Th s m y be obt i ed il the expe iment r d tract th ubject f om th timulu he is suppo d to j dge Th ac acy f p rcepti n uffe s Th xp ri m nte m y equ re the ubject t fix h s y on a po nt i on d of th pre nt d timul that its m ge fall on th p r ph ral eti a Only the most gene l features of the bject are the re port bl nd if it is atyp al in ny re p t the p c pt w ll be in act

St a g d famili things A ol rve who i g e ted w th wh lly n l t m lu annot d t f it Man *fo eign rds re t he rd as* b g d ff r t f m one anoth r and n el p t t d n t look d ff e t le th s a pat el se t g the a d mpa ed O ly gr s r fam l a dif f ren es ted Th no e at u ng a mic o c p m t lea n what t l ok fo and h w t per e the btl t es of ol r a d t u t re in th l d of t ue unde examin ti n W th u h timuli h eve g es ng gi es way t exa t p r ept n prai t n ob ervat c nt nu

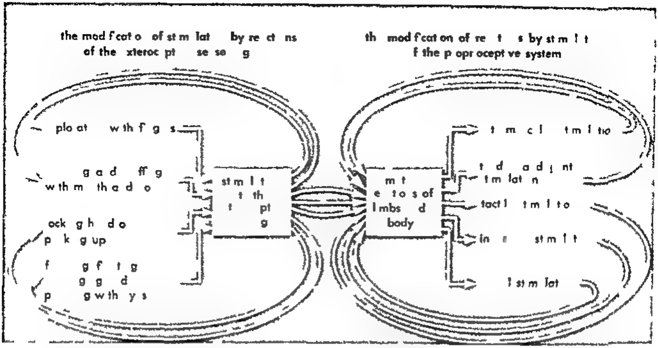
Oh h dd n p t of th gs As the *med l p f* know th nterp etat n f x y ph t graph th d agn i f r e d a e ubject t to In p ri th may be due to la k of pe pt al k ll but t m y l o be due to the intri n po rty of the nf rm t n a l ble n sensor i mul t n Howev actı ly he a h th pe i er m y n t be able t d tect l d i d i f th t t t of aff Th ame rule m y h ld t d t ng the at ges f wi es or timati g th ch r t f a qu inta e

E pe m tally mpo h d t m latio It has l g been k wn th t n y detect n bec mes g es i g h the lu l t en gy appl d t on f th ry ha l t ffi i tl red ed and that n ory d scrimination becomes gues ing whe the absolute diffe ence between two e ergie is re d ced The th s l old inten ty f light ound taste o touch is defined a that at which the frequency of correct gu s reaches the l el of chance Sim ilarly the d fference thre hold is that differen e wh ch di des chance gue ing fr m better than chance gue sing (*se* SEN ATION) *Perceptual ex* perience becomes gues in in the same way when the patter in light or ound m imp veri hed or di t rted The patte n f light an b blurred by opt al d i e r ve led by gl re r reduced in ze t a thr hold le el th patt rn of sound can be ma ked by n e or di rupted by electron c mea or d torted u t l peech be me unintel li ible A ommonly u d vis l d v ce is the tachi t scop wh ch reduce the du ati n of the timulus pictu e to a fraction of a second or l s Whichever of th e methods s u ed th re ult is the am the p orer th pattern the le accurate are the re port f the b erver

No st mulati n When all channel f stimulat n known to the expe iment r ha e be n eliminated g e ses can still be made by the ubject They are ord n r ly c rre t o ly by chan e But certain ex perime ts on the gue sing proce ing h dden ards and many jud ment m t m s yiel l a ta ti ti ally s gn fic nt depa ture f om hance This i ften tak n as idence for a kind of e t a ensory pe ept n nd for an unknown cha n l of timu lation *See* EXTRASEN ORY PERCEPTION (ESP) Howe e nte e t ng these r ult th y h uld n t be cons dered to apply to per pt n but imply as an unexplained fact in th tudy of g ss ing They h uld not be onfu ed with the experiment weak stim l t on in e no ariable has b en d s ove d n ESP exp riments which co l tes w th the frequ n y f c rrect g s es F r the same ea on as th e ults now tand they do not pro de eviden f r an u k w cha el of stim lati n

Cont ad cto y stimulus info m tion Vis al p t terns c n be de igned wh h are ambiguo that is wh h ndu e ther of two perc pti n one in om p tible w th th othe Pa nter l a e m nip lated l e nd nt ur n th way b t th G talt p y h l g sts we th f t to wo k y temat cally w th mb gu us draw ng and to demonstrate the ole f ton s n hapi g phenomenal bj t and pr du g wh h t on time l ok l ke filled sol d sp c and t an ther time l k u f lled mpty spa e It m ght e m b e that one timulu pa doxi lly an a ou e two p rcepts but t i m e l kely that tw stimulu facto the ame d awi g re p tted ag in t e anothe To con s der bl ext nt the b erver an sel t that f tor th t tal timulu t wh h h w ll espond or hi el t on m y be infl nc d by the experi mente

In all the e k nds f app hens on the t mul s ppl d does n t m t determ ne the spon made fo the l tter is ubject t the nfluences A g e t var ety f ch fluences ha b n st died in the effo t t g t at th nature of th perceptual



The feedback loops for exploring or enhancing external stimulation and those for controlling behavior

The angular lines represent physical actions; the curved lines represent . . . actions

considered there is the kinesthetic. This is served by various kinds of *receptors* in the muscles, tendons, and joints and by still others in the inner ear (*see* KINESTHETIC SENSATION). Conceived broadly the sensitivity of an individual to the behavior in which he is engaged is much more than a single sense. It includes all stimulation produced by responses, and this extends at least to touch and vision. When handling things or walking about, a man feels his activity by the changing pressures on the skin and he sees it by the *changing patterns* at the eye; he even hears it by the noises at the ear unless he is careful to be silent during manipulation or locomotion. There are many channels for this "feedback" from response, some of the stimuli being inside the skin of the organism and some being outside, but all of these circular loops have a common function: they keep the individual informed about the outcome of his muscular movements and about the progress of his action. They also serve to guide or control behavior inasmuch as they define the terminal act of a course of action and indicate the degree to which it has not yet been reached (*see* CYBERNETICS).

The kind of perception which is produced by action is not as familiar as the kind which is produced by the environment as such. It is harder to investigate and it is only beginning to be understood. But obviously the two kinds must be interlocked. In locomotion, for example, an animal needs to perceive both that he is moving through his environment and also where he is going and how close he is to his goal. For this he must be able to perceive the layout of his *environment*. The visual control of locomotion, therefore, is not separable from the visual perception of space. A walking man has to be able to feel and see himself moving and, at the same time, to feel and see the motionless ground beneath his feet. This necessity raises the question of the so-called "*constancy*" of *environmental* perception, which will be discussed later.

Relationship to the motivating of behavior. If the perceptual process acquaints the individual with his own actions as well as with the environment, the question may be asked whether it also informs him of his own inner needs and of those outer objects which afford satisfactions of his needs. Does perceiving motivate action as well as being itself a kind of motivated act? *Such questions raise* difficult theoretical issues. To some extent an animal or a man can discriminate among or perceive his own biological needs (*see* HUNGER; PAIN, DEEP; THIRST). Likewise an animal or a man can identify food, mate, shelter and other objects of his environment, beneficial or noxious, with considerable success. But the relation of these disparate facts to the motivation of behavior is a controversial question (*see* MOTIVATION). A man who comes across a rattlesnake in his path perceives and feels and acts all at the same time, and the psychologist's arbitrary separation of these processes fails.

Introspectively, percepts seem to have a subjective reference as well as an objective reference, but some have much more than others. In a painful experience the subjective pain dominates, whereas in a visual experience the object dominates. But even in visual perception there is the implicit sense of "here," and in auditory perception there is the awareness of "now." However objectively oriented one's experience of the world may be, there lurk in the background a variety of tensions, feelings, *emotion*, *the image of the body* and the consciousness of self. Philosophers and psychologists have long recognized the importance of these subjective facts. But they are not easily put to experimental test and so are given little emphasis in scientific psychology.

Guessing supposing or surmising Con id r at ha bee mad up to thi point f the ki d f pe cept characterized b a feeling of certainty nd a testable d pend n e on th st mulati n of sense org ns. Ther ar man kinds f app ehen n, h wever whi h a e les certain and less ob i l d pe dent o t mulati They are n t rd n rily alled perce i g but gues ng or ppo ng o rmi ng Th m a gr t diff re c between bservat on and nf r ce but at th ame tim th e i ften s ppo ed to be an el ment f infer e n all perc pt on even the implest k nd This arises from tw theor ti l a sumpt n fir t that o ly the so-called sen at ns are cert in and cl ar a d ec nd that they are mean ngles On thi umpt som theory f per eptual proces whi h upplem t th sen at on i neces ary Co eq entl th e h been a g eat i terest in the arious t pes of unc rtain app ehe n w th the h pe that they will eveal th nat r of the internal co trib ti n t sensory data.

Ma y kind f gues ing and ts a ants may oe u b t the a n t ea ly d sti gui hed by ntro-specti n. Th e a e e pe mental m thod h w ev f prod g some of them a d these may be li ted gi g partial) ficat n

C l s bs reat o d r d d attent n. Th s m y be bt ined if the e perim nt r d t ct the ubject f m th timul he is upposed to j dg Th cu cy f per pt n uffers The exper m t r m y equ e th ubject t fi h e es n a point to a de f th p es nted t m lu so th t t imag fall n the pe iph ral r t na Onl the most g e al featu es f the object re the re-portabl nd f t i typ cal a y resp t the pe c pt w ll be in xa t

St a g d nl mil a thi gs An bserve wh p esented w th a wh lly el st m lu c t d tify it Ma f gn w rd a n t he rd as be ng diff e t f m ne another a d novel pat tern d n t look diffe ent nles they r put close t the a d c mpar d fi lly gr o f m l ar d f f n es re noted The no ce at u ng *micro-* p m t l arn what t look f a d h w t per th bil t f e l nd tru t re i the slide of t su nde am at W th h t m li li wev r gues ng gi es way t ex t per pti a p a t b rr t one t ues

Ob A dd p p ts s f th gs A th med l oles kn w the nt rp et t n of x y ph t graph th di gn of re d ea es t ubject t rs l part, thi may be d to l ck f pe ept i k ll but it may al li due t the ntrin po rt of th i f rm t n a lable n ensory i m lat n H wev r ctt ly h r hes the p ma n t be bl t d tect al d ind t s f th true t t f aff Th me l ma h ld f r d tectin the t nt ges f w n est m t g th h a te f o a qua t e

Exp rim t lly impor n h d st m l ti It ha l ng been k wn that so y d t ti n bec mes gues i wh the bsol te gy ppl d t of the se ry ha l uff tly ed ed a d that sensory d scriminati n bec mes g es ing wh n the absolute d fference betwe n two n rgies i re-d ed The thresh ld inten ty of light sou nd ta t or t uch is def ed a that at whi h the frequency of correct g es es rea hes the le el f cl an e S m ila ly the diff rence thresh ld i d at diff r nce whi h di des cha ce g ies ing fr m bett r than hance gues ing (se Sr ATI N) P rcept al ex per ne bec mes gues ing in the me way wh n the pattern in light r sound i impo ri hed r d t rted The patt rn of l ght an be ll rred l y optic l devi es s iled l y glare r red iced in ze i a th esh ld level the patt rn of sound an be ma ked by n i e or fi rupted l y electr nic mean r d t rted ntil peech becomes unint l ligil l A comm nly u ed i ual devi e i tl ta l i t sc pe wh h reduces th durati n l the t mulu p etu e t a fract n of a second o les Wi ches r of these m thod i u ed th res lt i the am th poorer the p ttern the les acc rate a e the re-ports of the bserver

No stimulati Wh n all hannel of tim lati n k wn to the xperim nte ha been l minated gues es an st ll be mad by th ul ject Tl ey are rdina ly correct only l v h n Bit c rtain ex periment on the g es i g proces u i g h dd n card and ma y j dgment scm times yi ld a ta ti t c lly ignific t d parture fr m h n e Th t oft n taken a evidence f r a kind f e trasensory per epti n and f r an unkn wn cha n l of tim lation S e EXTRASEN ORY PERCEPTION (ESP) If wer a nt resting these result th b l l n t b con de ed t apply to percept n b t mply a an u expla ned fact in th t dy f g es ing They h uld n t be confu ed w th the experime t n weak st mulat n sin e no va abl ha b en dis-co e ed in ESP expe ime ts whi h c relates with th fr q ncy of c rrect gues es F r the same r a so s th results n w tand the d n t pr id de e f r a unka wn hann l of t mul t n

Co t d ct y stimulu t f m t n l i i l p t t s an be de igned which ar aml iguou that i whi h ind ce e th r of tw pe pt n ne (ne m p tibl w th th ther Pat t hs e man pul ted l nes and c nt ur in thi w y but th Gestalt psy hol g t w th first t w rk tematically w th aml guou dr w ng and to dem n trate the role f conto i in l aping phen menal l ject nd p odu ng gi s which one tim look l ke filled r sol d p e a d at nother t me like unfill d empt pac It m ght m here that t mulu pa d x cally an arou e two p rcept but it is m re l kely that t o t mulu f t rs in the same draw g e pitt d ag in t n ther To a con id rable xtent th ob ers r an select that f tor n th tot l st mulu t wh ch h will respond r h lect on may b nfl nced by the expe i m nter

I all th kind of app h s on the stimulus ppl ed do s not eem t determ ne the response m d f th latt ubj t t oth r nflue ces A gre t va ety f such i flue ces ha b n stud ed n the ffo t to g t at th n tu e f the perc ptu l

process when it is not strictly bound to the stimulus. The influence of verbal suggestion on perception has been demonstrated, as well as an influence of past experience on perception, an influence of emotional prejudice on perception, an influence of cultural background on perception, and the like. But it should be noted that the more demonstrably perception is influenced by these factors the less it is like discerning and the more it is like guessing.

The nature of the subjective component in apprehension, whether the enrichment of stimuli or the organization of stimuli or something else, is not clear. Theories of the process are a matter of active dispute in psychology. The classical theories of the process have been described by E. G. Boring, the major historian of scientific psychology, and contemporary theories are represented by the authors listed in the bibliography. A consideration of these theories is not given here because such theories can have no firm basis until the extent that ordinary perception is a direct function of the variables of pattern stimulation is known. For that knowledge other methods of investigation must be used.

METHODOLOGY OF PERCEPTION

Methods of studying sense perception. The best way to investigate the perceptual process is to induce it artificially, that is, to construct an apparatus which will deliver to an individual the necessary stimulation. The experimenter then has to vary this stimulus in such a way as to obtain from the individual reports, judgments, or discriminative reactions which are a function of the variations. This is the psychophysical procedure by which sensory reactions are studied. *See* PSYCHOPHYSICAL METHODS.

When perceptions are studied, the procedure differs in that the stimulus must be a pattern or sequence of light, sound, pressure, or the like. This requirement puts a strain on the ingenuity of the experimenter, for the systematic variation of pattern or sequence is not easy and the artificial production of stimuli which imitate those of the natural world is an elaborate and sometimes expensive process. It is not surprising, therefore, that in most of the existing experiments on visual perception the patterns of light are those which can be reflected from line drawings, pictures, or nonsense forms. The experimental work of the Gestalt psychologists is largely based on stimulus material of this sort. There is an increasing tendency, however, for experimenters to manipulate and control the variables of patterned light, as is evidenced by the current interest in optical "texture." For example, the perception of a solid surface can be induced where no solid surface exists by an optical arrangement in which the light entering the eyes of an observer is patterned with a sufficient degree of density (J. J. Gibson et al., 1955).

Pictures, motion pictures, and binocular stereoscopic motion pictures are ways of approximating the natural input of the eye to an increasing degree. But the resulting perceptions lack the ultimate degree of realism because the pictures usually represent only a small sector of an environment. Methods of reproducing more of the total optic array have been devised, however, in the form of "simulators" for the purpose of military training. The visual input of a helicopter pilot or a tank driver can be imitated by wide-screen projection methods. Moreover, the motions in this field can be made to depend exactly on the control reactions of the driver or the pilot in a "mock-up" of the situation, so that the visual feedback acquaints him with what it is like to control the vehicle. The panoramic motion picture, the Cinerama, provides an optical array which more nearly approaches that of a real environment. Such presentation, if systematically varied and guided by theory, promises to solve many of the problems of visual perception.

For the study of auditory perception the artificial production of pattern and sequence is not so difficult as for visual. The input to the ears is easier to control than the input to the eyes. Recent advances in electronic and mechanical devices enable the experimenter to manipulate air vibrations in the physically complex ways that are characteristic of informative sounds. Not only can natural sounds be recorded and reproduced with fidelity, they can also be produced to order. Speech sounds, for example, can be synthesized. From this it is only a step to the psychophysics of speech perception.

When animals or young children are used as subjects in perception experiments, the experimenter must be content with behavioral discrimination. Verbal discrimination and description by a human adult provide somewhat more direct and subtle evidence of the perceptual process. But the methods are fundamentally the same in that they consist of establishing the dependence of responses on stimuli.

The controllable types of stimulation for the experimental study of perception depend on the kind of energy to which the external receptors will respond, whether optical, acoustical, thermal, chemical, or mechanical. Examples of uncontrollable stimuli are the force of gravity as registered by the inner ear, which cannot now be experimentally eliminated, and the stimuli originating within the body, which cannot be experimentally controlled. If a pattern and sequence of stimulation which ordinarily arises from a real object or event is applied to the sense organs by an experimenter, the object or event will be perceived as if real and with all its richness of meaning. If the variables of adjacent and successive order in the stimulus are manipulated, the phenomenal object will vary correspondingly. There is no difference in this respect between the distance receptors and the contact receptors, that is, for example, between the seeing of an object by light at the eye and the feeling of an object by impact at the skin. Both light and mechanical impact ordinarily carry information about the substances in the environment, albeit somewhat different information. The ability to apprehend

lid ty at a d tance by means of l ght is n mor spe al pr bl m for percept on th n the ab l ty t pp ehe d sol d ty at z o di ta e by t uch r c n er ly pe cept o of a tla e bv t h s n mo e elf xpl nat r than pe ce v ng t l y ight In e the ca e me p perty of the t m lus mu t p c fy ol d ty

A ib t s mu t be t c nta t w th the t g e d rt b t tel t m t h tou hed so that its text r r t mp r t re may b f lt One mu t e me f i ly lo e t a cbje t r de to mell it l at l rg n mbe of its pr pe t es can be identif ed fr af f it e n be een The pr pe t e that bl ch identificat o of a object are c l r te tu e h p z d stan e m b l ty its plac n the l y ut of rfa e mpr ng the r t of the e r m nt a d t id ntity that t e prope t es that d ting h t f om ther bje t If it i a n sy bje t r being wh ch vocal es ident fi cat an oft n be made e n in da knes or ar d a o ne All uch d er minat n may b te ted experimentally Taken t geth r th y make p the p pt n of the natu al w ld The inf r m t n wh h th nd du l obta one rning the tate of th w ld a d h tuati n in it i c n eyed to h m wh lly by tim lati n

PROBLEMS OF SENSORY PERCEPTION

Th p bl m of pe c pt on ed to be formu lated ft des b ng th en tion of col r l i ht e p t h lo dne *p e u e w rmth cold* pa n t ou lt b tter and so n The p ob l ms on ted f ch qu t on a how space t me f m nd m t o a e p e ed Th were l o th q t s f h w obje t a e d e ed d h w th m g a p ce d M *t pa* l ng w the p bl *m* of xpla n g the nstan y of ph m n l bj cts i the f e of th fact that th et al m ges d n t eman ont t ev n f o m m nt to the ext Th l te atu *of these* p blem xt e (E G B ri g 1942 J J G b n 1950 M D Vernon 1952) A at t mpt will b m d h e t ref rmul te th pr b l m ch a way a t epr ent m dern dire u f e h Th re fi st the per epti n f e t o me t l pa e ec d the p pti n of pe m n nt bject a d thi d th per ept n of h g s nd ev nts At a highe le l of omplex ty th n a wh le e i s f p bl ms c ce ned with the pe cept o of othe *per ons* f the r a ti n a d f social timuli th y m t n tably wo ds

Environmental spaces It i ery d ubtful that the nfant fi t s pat hwork f col rs t two d men s and the gr d ally learn to nterp t the p t he n r l et a d ar *a r us d* t e s away fr m h m It m l kely th t wh t th f nt s an u d ff t at d but by n mea a fl t p ctu Th theory th t i s a fl t pi t e h we e ha b t gl t fo l g and mu h p rt f th h t ry f W t rn th ught th t t i w d ly taken f r g nt d Th l es fo the nt rp etat n f d pth d d t n r s id t b li a pe pect app nt t rpo tio sh d w nd aerial per pectiv The are the monocular sign of d tance and t geth r with apparent mot n that furni hes the parallax lue and retinal image dis par ty whi h s ippl es the l nocular cl ie f rm ba e f r such int rpretati n Thi is t s a mixture of fa t taken fr m painting phy ic and phy iol gy

A simpler q esti n is h w t rrestrial animal in cluding men percei e the terrain The q ti n can b extended t indi idual terrai features such a cany n f rest room c rrid rs r ad air lanes and e n th plan tary sy tem ach item h wever c ncerns places r per fic en ir nm nt rathe than empty pace The in estigat r i then led t a lyze the array f light projected t a st tion point in a gi en envir m nt th n to a traveling stati n po nt a d finally t the diff r nt t t n point f tw eye Variables in th pro jected light whi h pecify th pr perties of the nviro ment can thi be d red in luding th r es ion the lant and the di ntinuiti es f sur fa es Th nf rmat n i ca ried l n var ables of tru ture and tran f rmati n P rspecti m ti n pa llax nd l i ocular di p rity can be treated a t mul s variables in te d f clues and the tim lating *apacit es* of these ari bles can be tested *xperim ntally*

Concurr nt gradi nts f p tt *rn* of *m ti n* and c f d par ty a haract ri t c f th l ght reflected fr m a ont nu us fac like the g o ind In addi *ti n there* i u lly the cuta eou timulati n fr m c t ct with the gr und and alway the f *rce* f *gr ity cting* the inne ar and the muscles If the p rcept n f gr nd pla can thu be ac ou ted f r it pr ides a l teral b is f r und r *tand ng the* per pt on of th r pecial e i n ments and place

Surfaces and permanent objects T xture or p ttern in light pe ifi s some thing *r e in in that d rection* text eles l ght pec fies n th ng in th *t directio* The former typi ally mes fr m the e rth th latte fr m the ky Ag in t either ba k g o nd ohe ent pattern with a e t ur p ifies a d lim ted bject i that d re ti Stati ary ol *je t t gether with the* g ound e tit i the per m ne t e i onm t Such objects are of man types ob ta l s to locomotio or goals t be ap proa hed vant ge po nt or helte s ed ble b sta e or dangerous one Th y ha e t be di crim nated and ident f ed by c lor te ture shape and size a to re ct approp iately to them The quest on f how this s poss ble n ked by psy ch logists The proj cted sh pe and s ze of the ob j cts a n v the ame f m mome t to the next as th indi d al m ves about More r the ntens ty d col r of the light r flected fr m them does not tay consta t from n n to su t *Th* is on way of putt ng the p blem of the appar t co t n y of ph omen l bjects T tual fact th p j cted ar y f m the nti permanent en onm t, gro d a d bj t alike undergoes a nti u per pe t ve t a sf rmati n whene er the p c i e mo It i a quest n n t only of

why objects stay constant in perception but also of why the ground does.

Although various roundabout answers can be made to this query, the simplest is that there are both variant and invariant properties of optical stimulation under transformation, and that the invariants are the stimuli for the perception of invariant objects, that is, permanent and rigid ones. For example, the kind of texture that a surface possesses remains invariant, rectilinearity remains invariant, and such *properties as triangularity or quadrangularity* remain invariant. The variant or changing properties of the continuous transformation, on the other hand, are stimuli for the perception of locomotion. On occasion one may get the impression of a nonrigid or quasi-elastic environment during locomotion, but this is a secondary, not a primary, phenomenon. The above answer would explain how an individual can perceive the permanent layout of the environment and perceive himself moving through it, both at the same time.

The invariants in an array of light which specify the color of a surface despite changes in the illumination of the whole layout of surfaces are not yet fully understood, but there are a number of relational magnitudes which might serve, and progress *is being made in discovering them.*

If the momentary retinal pictures, shifting with every new fixation of the eyes, are taken to be the stimuli for vision, as physiologists assume, the fact of permanence in perception borders on the miraculous. The situation is clarified when it is realized that retinal images are not stimuli but incidents in the exploratory activity of the eye, which function to register the ambient light at a given location. There is a sequence of overlapping images, to be sure, for the exploration must operate over time, but the particular sequence is largely irrelevant. The stimulus for the visual system is focusable light, and this is stable and permanent for the given location. The situation is not unlike that of exploratory touch with the hand and fingers moving over the edges of an object. The changing pressure patterns on the skin appear to be wholly incoherent, and indeed the sequence may never be twice the same. But the invariant features of the transforming pressure patterns are perfectly coherent, and these are registered. These specify the permanent shape of the object.

Changes and events. Within the permanent environment described above there may be moving objects, and their motions may be either rigid or nonrigid. Substances in the solid state generally move without deformation in accordance with mechanics; liquids and gases (streams, clouds, fire) generally undergo deformation. The motions of animals, including the expressive movements of human beings, are of the latter sort. Both types and many subvarieties of such movements are distinguished by vision. The projected motions which present themselves to an eye are all geometrical transformations. With this as a basis, the question is how the rigid motions of objects can be distinguished from the elastic changes. Putting the question differently, why are the perspectives of the same object not confused with the changes that would transmute an object into a different one? The answer may be that the transformations in question belong to different "groups," and that the eye registers the difference. In fact, both human and animal eyes seem to be very sensitive to the types and parameters of geometrical transformation.

When a door opens, the optical rectangle becomes a trapezoid but the door is seen as rigid and turning. The variant component of the stimulus yields change of slant; the invariant component yields rigidity or constant shape. When an amoeba elongates itself, the same invariants are not present; elasticity or changing shape is seen.

The perception of even more complex events of the natural environment, such as the collision of two solid objects, is beginning to be studied. The optical stimulus for the impression of one thing moving another can be isolated and, as A. Michotte (1954) has demonstrated, the experience is more simple and direct than might be anticipated.

Persons and the cultural environment. In addition to the environment of postures, locomotion, *and manipulation, there is the complex environment* of social behavior. Not only solid objects but social objects are perceived. Other individuals and their actions, including facial expressions, gestures, speech, writing, pictures, music, and symbols, are all sources of visual and auditory stimulation. This is the area in which a great deal of research in perception has been concentrated because these stimuli and the corresponding perceptions preoccupy human life. But this is also where the perceptual process becomes most complicated and least direct. The pattern and sequence of the stimulus cease to be geometrically related to its object or event and begins to be arbitrarily related to it only by social agreement. The optical forms and acoustical sounds begin to be coded, that is, to have meaning by convention rather than by isomorphic relation. Signals or symbols will induce correct percepts but only if the perceiver has been educated in the social group which uses them.

The perception of persons may be fairly direct, as are the perceptions of even simple actions like attack, but the perception of their words is indirect. The understanding of language is only partially related to the producing of language, that is, to communicating. For the child, making speech sounds or written marks is part of perceiving them. Both must be learned, the spoken word along with the perception of speech, and writing along with reading. The child thus learns to seek perception [illegible] another individual as well as to have perception [illegible]. Communication is [illegible]ually circular, and there [illegible] feedback loop through another individual [illegible] the *kinesthetic, auditory,* and visual loop of self-stimulation. The ability to respond to the [illegible] of one's own vocal or graphic behavior in th[illegible]

ay as th s do is bas e t human kn wledge a d thought When the hild l e t per e th ngs n ooper t n with others th percept l proce s aches h gher tage than before

Th e are many refer ces in th ci tifi lit ra ture of experimental work on the perc ption of graph c mater al that i line drawi g pi tu ymb l a d en e forms But thi w rk is h rd t i te pret becau e timul s m t ri l ca ries a mi tu of intrinsi mean ng and coded mea ng Vi al f rm or l ne draw ngs have a vag e tatu wh h l e om wh e betw en ub tantial bj t d ymbol tr ci g on a su fa e Exper m nt in form perc pt on uff r f m th amb guity the ob erv r te d to per e both s m repr ented r l object and the l t ral m rk ng n th rf e th p pt bein a comprom e b tween them The light nt g the eye d not pecify eith r a full bstant al urf ce or a f lly symbol c art fact, but t h s some f ature of both

P re ng by way of od d t mult s a large fi ld f r e p ment l est g t n The m t ac t e tudy up to th pre ent has b en c nnected w th ommuni t y tem a d with bal mes ge (se INFOR IATION THEORY) The t dy of part lly oded t mul fa al xp ess on r mu f r ampl le s ad need A d the ientific de t ndi g f the on p es ntati p tures mad by mod n art ts i at pr miti e l l

P r i ng s n p rt a m tt r of fir t hand ac qu nt n e ndepend nt of l ngu ge It s al n t a kind of pe n e second h nd mod lated by th e t on of l guag The blendi g f th e m gly d par te infl ences i m n k led f th w rld is maj r theo et cal pr b l m wh h not y t ol ed [J J G]

B bl o phy E G B ing *S at on a d Pe pti th H st y f E rime tal P ych l gy* 1937 E B u wik *The C c pt of F m u k of Psy h logy* 1952 J J Gibson *The P pt o of th V s l W ld* 1950 J J G b n J P dy and L Lawre A meth d f ntr ll timulation f the t dy of p e p r pt n the pt al tun *I J E pil P y h l* 50 l 14 19 S K K ffka *P pl s f G st lt P y h l gy* 1935 A M h tt *Ia P pt n d la C usalit* 2d ed 19 4 M D V on *A Fu th Study f Vis al P p tion* 19 4

Perch

A t m wh h when p pe ly l m t d appl es nly t th ellow p r h *P c fla c s* a d its Eu o pe n l ti s

Th y ll w p ch on of the most c mm n of th fish s No th Am ica e pec lly n th Uppe Mi s pp and Gr t Lak s d a n a s It s f n f d fi h ad ly aught by n gl s at all s ns f th ye r In m ny lake t s n t p du ti a d t tt g if not se r ly fi hed

Th t rm p r h mm ly m su ed Fo exam pl th r fi h i f q tl call d red p h r

The y ll w pe ch P fla e e ; le gth t 12 i (Fr m E L. P lme Fieldb k of Nat l H st ry McG w-H ll 1949)

ocean perch th wh te ba s or fresh water dr im a e It n alled white perch and the g n ral t rm perch i u ed f r any f e tal fr h wat r sun fi hes parti ularly black perch or th green un fi h Se PERCIFORMES [J D B]

Perchlorate

A c mpou d which contains chlorin in th +7 x dat on stat and which i deri ed fr m per hl ric a id $HClO$ P r hl rates are m r tabl than chl rates chlorites or hypochl rites but are never theles e cellent oxid zing agent On heating per chl r t s dec mpo e into pota i m hl r de KCl and ox gen ga Beca e of their oxidizing pr per t es perchlorates find u i expl e and a oxidi ng agents in the l boratory

Pot um p rchlorates can be prepared by h at ing pota i m chl rate.

$$4KClO_3 \xrightarrow{\Delta} 3KClO + KCl$$

In a s de reacti n ome oxygen i liberated

$$2KClO_3 \rightarrow 2KCl + 3O$$

S di m pe hl r t s also prep red ommer cially by an electroch m cal proce Sod im chlo rate made from od um chl r de a d chl rine is the ta ti g materi l (se CHLORATE) The o dium chlor te is then electrolyzed with the n t re ct on at the an de bei g

$$ClO + H O \rightarrow ClO + 2H + 2e$$

Sod um per hlo te is then co erted t pe chl r acid th r m tall c salt S e CHLORINE HYPOCHLORITE OXIDIZING AGENT [E.E.WR]

Perciformes

The typ al pi y ayed fi h s al o kn wn by the d nal names Acanthopt ri nd P rcom rph Th s i the larg t rde of ert brate It in l d a d v s ty f st tu al type well as of ze f m a l ngtl f less th n ¼ to a weight of nearly 1 t n Th cha acter of the Pe ciforme include fin spin whi h ar ually pre nt a pel ic fin which if present us lly th rac r j g lar i pos t the pel gi dle u ally tta hed t th l ith a met mes onnect d by l g me ts th p lvi fin u ually w th sp and 5 soft ays, the l tte occ i ally reduc d the pect ral fin ba e m re or l ss ve t al u u lly pl ced well up

why objects stay constant in perception but also of why the ground does.

Although various roundabout answers can be made to this query, the simplest is that there are both variant and invariant properties of optical stimulation under transformation, and that the invariants are the stimuli for the perception of invariant objects, that is, permanent and rigid ones. For example, the kind of texture that a surface possesses remains invariant; rectilinearity remains invariant; and such properties as triangularity or quadrangularity remain invariant. The variant or changing properties of the continuous transformation, on the other hand, are stimuli for the perception of locomotion. On occasion, one may get the impression of a nonrigid or quasi-elastic environment during locomotion, but this is a secondary, not a primary, phenomenon. The above answer would explain how an individual can perceive the permanent layout of the environment and perceive himself moving through it, both at the same time.

The invariants in an array of light which specify the color of a surface despite changes in the illumination of the whole layout of surfaces are not yet fully understood, but there are a number of relational magnitudes which might serve, and progress is being made in discovering them.

If the momentary retinal pictures, shifting with every new fixation of the eyes, are taken to be the stimuli for vision, as they have long been assumed, the fact of permanence in perception borders on the miraculous. The situation is clarified when it is realized that retinal images are not stimuli but incidents in the exploratory activity of the eyes, which function to register the ambient light at a given location. There is a sequence of overlapping images, to be sure, for the exploration must operate over time, but the particular sequence is largely irrelevant. The stimulus for the visual system is focusable light, and this is stable and permanent for the given location. The situation is not unlike that of exploratory touch, with the hand and fingers moving over the edges of an object. The changing pressure-patterns on the skin appear to be wholly incoherent and, indeed, the sequence may never be twice the same. But the invariant features of the transforming pressure-patterns are perfectly coherent, and these are registered. These specify the permanent shape of the object.

Changes and events. Within the permanent environment described above, there may be moving objects, and their motion may be either rigid or nonrigid. Substances in the solid state generally move without deformation in accordance with mechanics. Liquids and gases (streams, clouds, fire) generally undergo deformation. The motions of animals, including the expressive movements of human beings, are of the latter sort. Both types and many subvarieties of such movements are distinguished by vision. The projected motions which present themselves to an eye are all geometrical transformations. With this as a basis, the question is how the rigid motions of objects can be distinguished from the elastic changes. Putting the question differently, why are the perspectives of the same object not confused with the changes that would transmute an object into a different one? The answer may be that the transformations in question belong to different "groups," and that the eye registers the difference. In fact, both human and animal eyes seem to be very sensitive to the types and parameters of geometrical transformation.

When a door opens, the optical rectangle becomes a trapezoid but the door is seen as rigid and turning. The variant component of the stimulus yields change of slant; the invariant component yields rigidity or constant shape. When an ameba elongates itself, the same invariants are not present; elasticity or changing shape is seen.

The perception of even more complex events of the natural environment, such as the collision of two solid objects, is beginning to be studied. The optical stimulus for the impression of one-thing-moving-another can be isolated, and as A. Michotte (1954) has demonstrated, the experience is more simple and direct than might be anticipated.

Persons and the cultural environment. In addition to the environment of mechanical contact and manipulation, there is the complex environment of social behavior. Not only solid objects but social objects are perceived. Other individuals and their actions, including facial expressions, gestures, speech, writing, pictures, music, and symbols, are all sources of visual and auditory stimulation. This is the area in which a great deal of research in perception has been concentrated because these stimuli and the corresponding perceptions preoccupy human life. But this is also where the perceptual process becomes most complicated and least direct. The pattern and sequence of the stimulus cease to be geometrically related to its object or event and begin to be arbitrarily related to it only by social agreement. The optical forms and acoustical sounds begin to be coded, that is, to have meaning by convention rather than by isomorphic relation. Signal or symbol will induce correct perception but only if the perceiver has been educated in the social group which uses them.

The perception of persons may be fairly direct, as are the perceptions of even simple actions like attack, but the perception of their words and acts ... The understanding of language is in part related to the production of language, that is, to communicating. For the child, making speech sounds or written marks is part of perceiving them. Both must be learned, the spoken word along with the perception of speech, and writing along with reading. The child thus learns to evoke perception in another individual as well as to have perception. Communication is usually circular, and there is a feedback loop through another individual beyond the kinesthetic, auditory, and visual loops of self-stimulation. The ability to respond to the products of one's own vocal or graphic behavior in the same

s bef r they bec me 10 or m re years old and then after flowering the plants usually d e. *See* A UAL PLANTS BIENNIAL PLANTS PLANT

[F D S]

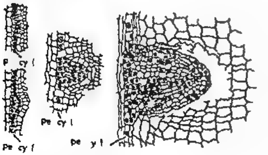
Pericycle

The per cycle i commonly defined as the uter boundary of the t le (see STELE) Originally peri ycl was interpreted as a band of cells between the phlo m nd the innermo t layer (endodermis) of the cort x Such p ricycle i commonly f und in r t and n lower asculat plant also in st ms In h gh r vascular pl nts h w er a di ti t layer of ll m y n t b present betwe n the phloem and th orte The h mogeneous gr ı ps of fibers located o the o t r bo ndary of the p imary phloem in ma y st m re n t per cyclic in origin but de el p th e l est p rt of the phloem who e rem i g cells a e oblit rated The per cycle if pr t may b mpo ed of pare chyma or scle e fyma lls with elat ely thin or hea ly thick ed wall It may be ne to ev al layers in radial d m ns o (F g 1)

Primordia f b an h roots comm nly ari e in the ll cy le n eed pla ts most f equ tly outside th xyl m r dg s (F g 2) The first cork cambium m y f o a i e in the pericycle of those oots that have secondary va cular ti sues In root a part of the vascular cambium it elf (that out ide the pri mary xylem ridges) originates from peri ycle cell *See* CORTEX PLANT ENDODERMI MERISTE I LAT ERAL PARENCHYMA PHLOEM ROOT (BOTANY) SCLERE CHYMA STEM (BOTANY) XYLEM *see also* PLANT TISSUE SYSTE IS

[V I C]

Fg 1 ( ) P rt f r et f oot f Act elb *M ll* l d g xylem d phl em ll icy l thi w ll d d ll d al d m (b) P rt f phl m P cy l th ck w ll d d 4–5 ll i d l d m o (b k r)



Fg 2 V rt cal t o f s h w g p g v g dev l pm t f s d ry t f m th p ricycl d g owth th gh th rt f the p m ry oot (F m G M Sm th A T tb k f G l B t y 5th d M m ll 1953)

Periderm

The protect e ti ue s tem of stems and roots compo ed of the co k cambium (phell g n) and its deri ati es cork (phellem) and phelloderm (pa renchyma) Cork occurs on the ou t ide the pl el loderm on the in ide of th cork caml ium (Fig 1) Pe iderm develops typically on woody roct and stems of dicotyledons and gymnosperm Herl a ceous tems st m of m nocotyledon leave and e en fruits n ay l kewise develop periderm although it may be limited in area and thicknes Some woody m noc tyled n develop a pecial kind of perid rm c rkl ke in tructure called t ried co rk becau e of cell arrangement Corky z nes of many herba ceous root are really uberized corte

Origin of periderm Typ cal periderm origi nates i more or les mature primary ti ues the cells of which res me mer tematic act ity The di i i ns occur parall l with the surface of the rgan that i in tangential planes In roots the c rk cambium u ually ari es in the pericycle and th subs quent formation of cork au e th sloughing of the cort x In stem any living tis ue outs de the va cular camb um may develop a ork caml i im Cells produced by th cambium t ward the outside d ffer ntiate nt cork as the ell walls become s berized and the p otopla ts disintegrate Some c rk cells appear to be empty other contain resin ous r tanniniferous ergastic sub tances The ph l loderm cells which are formed *toward the* in ide rem in ali e and often resemble the par nchyma ells of cortex r phloem Their rad al alignment with th cork ambium and cork pr vides the e i dence that they are part of the periderm The ph l loderm is s metimes called secondary cortex

Lent els ar h r cteristi f many periderms (Fig 2) The e structures a e len shaped reg ons f pe id rm wh re the co k cambium di ides mo e freq ently than els where and the derivati e cells a e not as ompactly arranged as the c rk cells The lenticels may develop before the rest of the periderm th cork camb um then spreads from l nt cel regi ns The lentic l cells may or may not be suberized All or part of the e cell g adually sep rat from one another In many plants layer of lo sely rranged cells alternate with compact lay rs wh ch are uptured pe iodically by th pro du t on f more cells undern ath The lls in the alt rn t ng zones ar called compleme tary cells nd cl ing cell r pe ti ly Fun t o lly len t cels are de ed t be o s f the periderm that all w g eou inte ch g between th int rn l g on f th plant nd th atmospher In th spect, lent cel se m to be ec ndary epla e me t f the tomata of the epide m

Yellow pe ch Perca flo escens (After G B G ode G eat Internat al F she e Exh b t o London 1883 U S Natl M se m B ll 27)

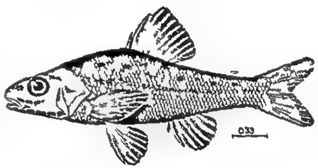
on the side an upper jaw bordered largely or en tirely by premaxillae orbito phenoid and meso coracoid ab ent a swimbladder without a duct a posttemporal which is usually forked articulating to the skull scales usually ctenoid ometimes sec ondarily cycloid ab ent or variously modified caudal fin with 17 principal rays (15 branched) or fewer hyoid arch with 4 branchiostegal rays at tached to the outer face of the epihyal and cerato hyal above the prominent angle of the ceratohyal plus 1–4 rays usually 2–3 attached to the edge of the ceratohyal below the angle the number rarely further reduced

Adaptive radiation Perciform fishes dominate the modern vertebrate life of the oceans and have done so throughout the Cenozoi The group fir t appeared in the Upper Cretaceous after which it underwent a rapid adaptive radiation many of the basic structural types as well as most major orders of perciform derivatives such as the Pleuronecti formes Tetraodontiformes and Lophiiformes were present in the Eocene A few families of perciforms have been notably successful in fresh water the Cichlidae in Africa and South America the Cen trarchidae in North America the Percidae in North America and Eurasia, the Anabantidae in south eastern Asia and many other families which have achieved limited success in invading fresh waters Other families including the Chiasmodontidae Brotulidae and Cyclopteridae ha e effectively adapted to life in the deep seas and still others such as the Scombridae Stromateidae and Cory phaenidae have become specialized for pelagic existence It is in the shore areas the offshore banks the coral reefs the coa tal beaches and lagoons and the intertidal zone however that the perciforms have attained their ultimate achie e ment Here the enormous variety attests the adap tive effectiveness of the group Because the knowl edge of classification is still imperfect no accurate enumeration is yet possible but a rough tally indi cates that the order contains 17 suborders about 137 families and nearly 1200 genera These figures are con ervative the number would be ubstantially increased by adopting the arrangement accepted by splitters An estimate of the number of included species p rhaps 8000 should be accepted merely as a rough guess po sibly in error by 25% or even more

Economics From an economic standpoint the Scombridae including the oceanic tunas and mack erels rank first among the perciforms The Sci aenidae or drums the Serranidae or sea bas e the Scorpaenidae or rockfishes the Carangidae or jacks the Cichlidae of tropical fresh waters the Percidae of temperate fresh waters and other groups support important commercial fisheries Some of the e and other families such as the Cen trarchidae or sunfishes the Istiophoridae or ail fishes and marlins and the Pomatomidae or blue fishes are valued in sport fisheries and hence are of great recreational and indirect economic impor tance *See* ACTINOPTERYGII FISHERIES CONSERVA TION [R M B]

Percopsiformes

A small order of actinopterygian fishes which is perhaps remotely related to the Beryciformes The group is also known as the Salmopercae Its char acters include single ray supported dor al and anal fins each with 1–4 anterior pines pel ic fin subabdominal in position with a minute spine and 7–8 soft rays pelvic girdle attached to the po t cleithra upper jaw bordered by premaxillae no orbitosphenoid bone swimbladder without a duct and body covered with ctenoid scales



Sand rolle Pe ops s t an mo tona (Afte D S Jor dan a d B W Eve m Th F shes of N rth a d M ddle Am ica U S N tl M e m Bull 47 1900)

Two families two or three genera and three Recent species of North American f esh ater fi hes comprise the order Eocene and Miocene fos il genera from North America are assigned to the group The species attain a maximum length of 6 in and inhabit sluggish or standing water *See* ACTINOPTERYGII BERYCIFORMES [R M B]

Perennial plants

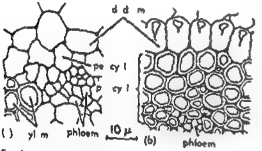
Plants which live for more than two year Tree and shrubs and many grasses edges and ther herbaceou plants are pe ennial Duri g unfa o able seasons the aerial parts may die but the root remain alive Some perenni l pr duce flowe and eeds during their fir t year and an ually the e after Some such s the apple bear no flower ntil their fourth or fifth year but bl om each year the e after Oth r perennials as the aga e bea no fl w

before they bec m 10 or more yea s old and then after fl ering the plants usually d e See ANNUAL PLANTS BIENNIAL PLANTS PLANT [P D S]

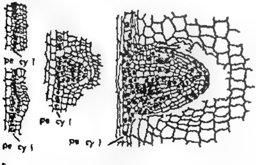
Pericycle

The pericycl s ommonly defi ed as the outer bounda y f the tele (s e STELE) Originally peri ycle wa i terp eted as a band of cells between the phl em and the innerm t layer (endodermis) of the rt x Such pericycle m commonly found i roots a d f we asc lar plants also in stem In high r ascular pl nts, how er a d stinct l yer of cell may ot be pr sent between the phloem and the cortex The h mog eous gr ups of fibers lo c ted o the outer bo da y of the p im ry phloem i man) stems a e not per cycl in origin b it de elop in th a l est part of the phloem who e re m i g ells are obl terated The pericycle if p es t may be ompo ed f p ren hyma or scl r n hyma cell w th el t vely th n or hea ily thick e ed wall It may be o e to seve al laye s in rad al d men n (F g. 1)

P im rd a f br nch roots comm ly arise in the pe i ycl n eed pl nts most f equently outside the xyl m r dg (Fig 2) The first co k camb um m y l o a e in th pe icycle of thos oots that



Fg 1 ( ) P rt f t a ect n f oot of Act a lba Mill l d g xyl m a d phloem P cy le th n w l d d ll od l d m (b) P rt f phl m P cy l th k w ll d d 4–5 ll f od l d me n (b o k t)



Fg 2 V rt l ct f t howi g p g devel pm t f c d ry ot f m th p cy l d g with th gh th rt f th p m ry t (F m M Smith A T tb k f G l y 5th d M m ll 1953)

have sec ndary a cular ti su s In root a part of the vascular camb um it elf (that out ide the pri mary xylem ridges) originates from pericycle c lls See CORTEX PLANT ENDODERMIS MERISTEM LAT ERAL PARENCHYMA PHLOEM ROOT (BOTANY) SCLERENCHYMA STE I (BOTANY) XYLEM see also PLANT TI SUE SYSTEMS [V I C]

Periderm

The pr tecti e ti u sy t m of stems and root c mp ed of the cork cambium (phell gen) and its d ri at ves c k (phellem) and phell derm (pa ren hyma) Cork oc urs on the ut de th phel loderm n the in ide of the cork caml ium (Fig 1) P r d rm d vel ps typ cally on woody root a d stem of dicotyledons and gymn perm Herl a ceous st ms stems of m nocotyledon leave and ev n fruit may l kewi e dev lop p rid rm altho igh it may be limited in area a d thi knes Some woody m n tyledons de elop a special kind of perid rm c rklike in structu e called st tied rk becau e of cell arrangement Corky zon f many herl a ceo s roots are really suberized c rtex

Origin of periderm Typical perid rm orig nates in more or less mature primary ti ues the c lls of which res me m ristematic acti ity The di i on occur parallel with the surface of the organ that i i tangential pl ne. In root the c rk c mb um usually a i es in the pericycle and the sul equent f rmat on of cork causes the sl ughi g of the c te In tems any li ing ti ue out ide th vascul r cambium may devel p a cork caml ium Cells produ ed by thi cambium toward th out ide d ffer ntiate int cork a the cell walls bec me suberized and the prot plast di integrate Some cork cells appear t be empty others contain re n o s r tanniniferu ergastic sub tances The ph l loderm cells which are formed toward the in ide r ma n ali e a d often resemble the parenchyma cell of cortex o phloem Th ir radial alignment w th the co k cambium and cork pro ide the e i dence th t they are part of the p riderm The phel loderm is metimes call d seco dary cortex

Lent cel are haract ri t c of many periderm (Fig 2) Th se structures a e len haped reg ns of pe iderm wh e e the cork cambium divides more freque tly than el ewh re and th deri ative cell a e not a compactly a ranged as the cork cells The lent c ls may devel p before the re t of the periderm the cork cambium then spre ds from lenticel regions The lenticel cells may or may not be suberi ed All or pa t f these cells g adually s parate f m one another In many plants layers of lo ely arranged c lls alte nate with compact l ye s which e rupt red pe d cally by the pro ducti n of mo e cell u d ne th The cell in the lt ting zone a e alled complementary cells a d cl s g cells respecti ely Funct onally l n ti l are c n d ed to b eg on of the periderm that all w gaseous interchange betwe n the nt rnal egio f th plant and the tm phe e In thi r spect le t els e n t be second ry replace m nt f the stomata f th epid rmi

Cork Cork may be ela tic smooth and uniform in structure Or it may also contain sclereids (hard walled cells) di tributed in various patterns Cork varies in thickness Commercial cork is an example of a thick cork Annual rings are known to occur in

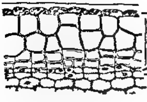
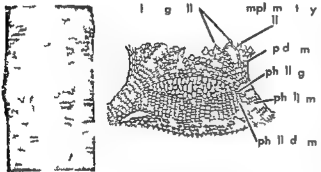
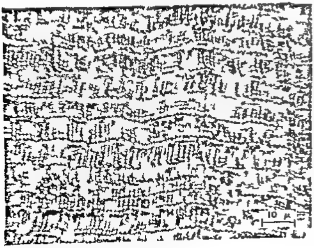


Fig 1 Pe derm C o sect o of supe f c al layer in tw g of *Popul delto d* the co k cambium a ose i the oute most co t cal cells and has formed fo lay s of co k cells a d one of phellode m the co k s *co e ed by d d to n f lled ep dermal cell (Fr m A J Eames a d L H Ma Dan l An Int d tion to Plant A atomy 2d ed M Graw H ll 1947)*



(a) (b)

F g 2 (a) Le t cels of older (*Al a a*) Th st m was 4 i n d am ter (f om *C L W l o a d W E Loom B ta y re ed D yde 1957*) (b) Le t cel of *Pr s a m n t n* e sect of st m A numbe of s ces e layers of c mpl ment ry a d clo g t su h b fo med a d th th ck laye f ph ll derm d p i w d nto th co t (f om *A J E m a d L H M Da ls A I trod ct o t Pla t A atomy 2d d M Graw H ll 1947*)



F g 3 R d al s ct on of pe d m of p pe b ch (*B t la p py fe Ma sh*) show g alte ate l y of d lly n rr w and broad ph ll m (c k) cell (F st P d t Labo t ry USDA)

cork (Fig 3) Some plants produce corky wings on their stems for example cork elm and sweetgum Roots and underground stems rarely accumulate cork Exposed portions of roots or rhizomes on the other hand may accumulate cork (or rhytidome) in much the same way as aerial stems

Corky zones develop regularly as spots on some fruits for example apple and pear in the styles of pineapple and as ridges on *Circaea* fruits In ome aquatic or marsh plants cork cells become T shaped so that the tis ue encloses large air spaces Such ti sue is an example of the so called aerenchyma Cork which forms in re ponse to wounding is similar to normal cork Periderm often develops in connection with abscission of leaves and other tructures it may precede this phenomenon or it may develop as a wound cover after ab cis ion *See* BARK CORTEX PLANT EPIDERMIS PLANT FRUIT (BOTANY) LEAF (BOTANY) PARENCHYMA PERICYCLE PHLOEM ROOT (BOTANY) SCLEREN CHYMA STEM (BOTANY) [H W BL]

Peridotite

A dark colored phaneritic (visibly ary talline) ig neous rock composed largely of olivine with smaller amounts of pyroxene or hornblende It is one of a group f essentially feldspar free rocks called ul tramafites (meaning extremely rich in mafic or dark colored minerals) As feldspar (calcic plagio clase) increases the rock passe into oli ine gab bro as pyroxene increases at the expense of oli vine the rock pa ses into pyroxenite As hornblende becomes the dominant mafic the rock becomes hornblendite Fresh periodotite i one of the heavi est (specific gravity 3 3 ±) igneous rocks

Composition Olivine is generally magnesium rich and forms rounded to irregular grains It is essentially the only mineral in the green sugary looking rock called dunite O thopyroxene is gen erally magnesium rich (enstatite) and the clino pyroxene may be diopside augite or rarely titaniferous augite Amphibole is brown or green hornblende and l ss commonly barkevikite Mica is magnesium rich (phlogop te) and colorless to red brown Acces ory minerals include chromite mag netite ilmenite spinel apatite and garnet A a riety of m ca peridotite called kimberl te occu s in pipelike bodies near Kimberly South Africa and carries small quantities of diamond Othe perido tites are platinum bearing Peridotite is us ally more o less altered to serpentine chlorite carbon ate talc and actinolite

Texture and structure M t peridotites are e en grained except a few which h w la ge ir regular pyr xe e grains enclosing maller grains of oli ine and magnetite Certain mine als m y be seg egated to f m banded and layered stru ture In some rocks elongate ol ine grains in l p allel orientation pr d ce a fl w tructure In th rs the texture uggests exte i e m vement and granu lation of ol ine crystals

Occurrence Perid tites are found s thin heets r len es interlaye d with gabl ro py n nite nd ano tho ite Here they appear to ha e differ nti

t d f m gabl r ic magma (ro k m lt) F ne e am ples in l de th e of the Stillwat r complex m Mo tana and th Tran a l S uth Afr ca Where f rmed s p pe pl g and d ke perid tite ap p i s t h ve l d little therm l effect up n the n l s n rocks Th suggests the m terial wa in jected a elati ely c ol ry tal m l ratl r tha a c mpl t melt (m gma) Many erpent ne ms n f ld m unta el n may epres nt altered peri d tite i trus f e l n ma y s ch l odies h w n rep ent p d t of m t m rphi m d m ta m t m. S e GABBRO IGNEOUS RO KS METAMORPHI M META OMATI I PETROGRAPHIC PROVINCE PYROXENITE [C.A CA]

Perigee

Th point n e t the Earth i th orl t f the M n o f a a t f i l at ll t At per g e the Moon i 5% cl r to Earth than at t mean di t e th rb tal e ent ty l e g 0 055 B th a e g the M d S n ul tend ne tly qual a gle la e l p e n a per gee la t ab t 5 mi a l p e n a apogee i a n lar Th li p p e Ea th ap g s the maj r axis of th rb tal ell r the l n f p de The dif f ent al a t on of the Sun n Earth and Moon a th l f ap d s of the M on t mo e f wa d i th b t l pl w th a pe d of 8 8 y a S M ON PERIHELION [G F K]

Perihelion

I a t my that p nt at o e t m ty f the m j r x a f th llipti al bolic r hyp r bol b t f pl t omet abo t th S n h th pl t m t l e t t the Sun The nt wh n pl n t r comet at pe hel n f ed t tl t me f p r h l f ag F Fa th th b t the thi d f J n ry at h h t m Fa th me 1 550 000 mil el t t the S n th n t me d i e of 92 900 000 m le S CELE T L MECH NICS OR ITAL MOTION [R L D]

Period (periodic phenomena)

Th t m nterv l f a n le petit n f a vary ng t ty f a ott n r pl me n whi h r p at it (f eg l ly The p d the proc l f the f qu n y S FR QUENCY (WAVE MOTIO)

Wa e h h l r gul ly ep at d t me ary ng t nt ti s e t m d p d (e PERIODIC MOTI N) I g n al ny c mpl x p r d wa e n be d ib d by F u naly the m l f nd e pa t al wa wh e p d e teg l mult pl f a ngl e d kn wn s th f nd m nt l p od f the mpl w e S WA E MOTION [W J C]

Periodate

A alt wh h t od n th 7+ d t t i d whi h d ed f m pe odic d l od d i k th f m m t p od c d HIO d m p i d d H I O nd p p rod d H IO The or po d g alt k wn al

Only th peri date f dium nd p ta ium ar important Sod m m taperiodat NaIO and po ta ium m tap r od te KIO are u ed a o i lizing age t in analyt cal chemi try S e IODINE [F F W R]

Periodic motion

Any m ti that rep at it elf ide t cally at r gular interval If $x(t)$ repre nt the di placem nt of any oordinate f th y tem at tim t a peri di c m t n ha the pr perty tl at

$$x(t+T) = x(t)$$

for e ery value of the vari ll t n t The fixed time interval T l tween repet ti n or tl e d ration f a ycle i kn wn a the *period of tl e m t n* Freque cy th n mler f repe ting cycl per unit t me and i n m rically equal to the rec procal of the period T

Th moti f the escapement mechan m of a w tcl the m ti n f the earth al ut the s in and the m r omplicated m t f tl rank h ft p t n rods, and pi ton i an ngine runn ng at u if rm peed a e all ex mple f peri di m t n

The vil rat n of a pian string after it i tr ck a d mp d per od c m t n n t tr tly p riod a di g t the definit n Alth ugh tl m t n e y n a ly pe t it If and w th a fixed peri t n time e h c e e i ycle ha a lightly malle ampl t d S e DAMPING

Any periodic moti n can be expres ed a F u ri r eries— m of ine and e term who fr quencie are i tegral mult ples f the frequ ncy f of the p iod c moti Tl u

$$x(t) = A + \Sigma_n A \; c \; (2\pi \; ft) + \ldots B \; \sin (2\pi \; ft)$$

wh e th A_n nd B ar c tant c ffici nt and the um may be tak n o er all p iti e i teg r alues of n Fo the speci l ca in wh h the coeff ient all v ni l f r > l s HARMO IC MOTION ee als FOURIER ERIES A D INTEGRALS

Many sy tem with more than n d g e of free dom who m t n is n t imply pe iodic re mul t ply per di Tl m ti n m y be sol ed into part (f r exampl l t ntal and tical c m p ent ad l a d t ng ntial mpone t) ea h (wh h s period c l ut w th period th t re not comme u at On e ampl is tl e v l rati n f a bell wh se o rton freq n e ar t imply e lated t the fundament l f eq ency Tl e m tion f the ol y t m is m lt ply peri d c be au it nev xa tly epe t i If e en th gh a h plan t m es p iodi lly Se VIBRATION WAVE MOTION [J M KE]

Periodic table

A tabl f the l m t wr tt n i que n th d f t m c numl r r t m w ght l a g d in h r zo tal ws (pe i d) nd ti l l m (gr p) t all t at the e f s mila tm i th p pe t of th el ment a a pe i d fun t n of th q ce

Alth ugh th p ple f th pe d r ng me t w s firmly t bl h d ly a e tury ag

PERIODIC TABLE OF THE ELEMENTS

Ia	IIa	IIIb	IVb	Vb	VIb	VIIb	VIII	VIII	VIII	Ib	IIb	IIIa	IVa	Va	VIa	VIIa	0
1 H 1 0080																1 H 1 0080	2 He 4 003
3 Li 6 940	4 Be 9 013											5 B 10 82	6 C 12 011	7 N 14 008	8 O 16 000	9 F 19 00	10 Ne 20 183
11 Na 22 991	12 Mg 24 32											13 Al 26 98	14 Si 28 09	15 P 30 975	16 S 32 066	17 Cl 35.457	18 Ar 39 944
19 K 39 100	20 Ca 40 08	21 Sc 44 96	22 Ti 47 90	23 V 50 95	24 Cr 52 01	25 Mn 54 94	26 Fe 55 85	27 Co 58 94	28 Ni 58 71	29 Cu 63 54	30 Zn 65 38	31 Ga 69 72	32 Ge 72 60	33 As 74 92	34 Se 78 96	35 Br 79 916	36 Kr 83 80
37 Rb 85 48	38 Sr 87 63	39 Y 88 91	40 Zr 91 22	41 Nb 92 91	42 Mo 95 95	43 Tc (99)*	44 Ru 101 1	45 Rh 102 91	46 Pd 106 4	47 Ag 107880	48 Cd 112 41	49 In 114 82	50 Sn 118 70	51 Sb 121 76	52 Te 127 61	53 I 126 91	54 Xe 131 30
55 Cs 132 91	56 Ba 137 36	57 La 138 92	72 Hf 178.50	73 Ta 180 95	74 W 183.86	75 Re 186 22	76 Os 190 2	77 Ir 192 2	78 Pt 195 09	79 Au 197 0	80 Hg 200 61	81 Tl 204 39	82 Pb 207 21	83 Bi 208 99	84 Po 210	85 At (210)*	86 Rn 222
87 Fr (223)*	88 Ra 226 05	89 Ac 227 0															

LANTHANUM SERIES

58 Ce 140 13	59 Pr 140 91	60 Nd 144 27	61 Pm (147)*	62 Sm 150 35	63 Eu 152 0	64 Gd 157 26	65 Tb 158 93	66 Dy 162 51	67 Ho 164 94	68 Er 167 27	69 Tm 168 94	70 Yb 173 04	71 Lu 174 99

ACTINIUM SERIES

90 Th 232 05	91 Pa 231	92 U 238 07	93 Np (237)*	94 Pu (242)*	95 Am (243)*	96 Cm (247)*	97 Bk (249)*	98 Cf (251)*	99 Es (254)*	100 Fm (253)*	101 Md (256)*	102 No (253)*

*mass numb r of most stabl known isotope

there has been much debate as to the most suitable form of display A widely accepted modern arrangement is presented in the accompanying table which is commonly referred to as a long table

Each element represented by its symbol occupies a eparate quare of the table together with its atomic number and atomic weight The sequential arrangement is in the order of atomic number

The table divides the elements into nine groups designated by numerical column headings and seven periods Se en of the nine groups are further di ided into a and b categories the a elements often being classified as main group and the b as sub group elements Two rows of elements (the lanthanide or rare earth series and the actinide eries) which on the whole are best classified as members of group IIIa occupy pecial positions outside the main body of the table as they cannot be included conveniently in their proper positions in periods six and seven

The following sections will serve to illustrate some of the correlative features of the periodic arrangement

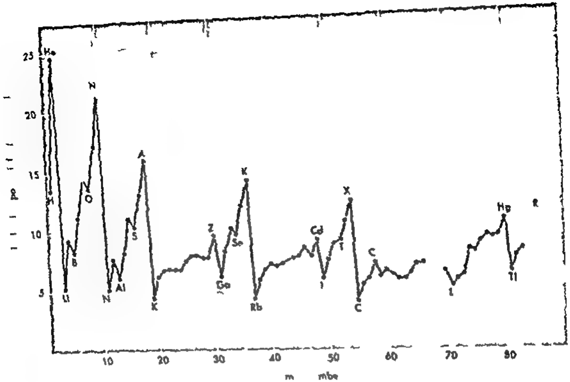
Valence In general elements in the same group display a similar valence which is numerically equal to the group number The rule holds most firmly for the main groups I through V less so for the subgroup elements and still less for the elements of groups VI VII and VIII Among these latter the group number valence s more readily achieved by the heavier as compared with the lighter elements (Group 0 elements are distin gui hed by an almost complete lack of chemical reactivity and hence show zero valence)

Metals and nonmetals The periodic table effects a natural division of the elements in th ir elemental or uncombined state into metals and nonmetals The nonmetals are confined to the li_hter elements of groups IVa through VIIa Between the area occupied by the typically metallic elements and that occupied by the nonmetals there is a somewhat ill defined borderland of elements (germanium Ge arsenic As antimony Sb tellurium Te and polonium Po) whose properties are transitional between the metallic and nonmetallic element

Acid base properties of the oxides of the elements Associated in a general way with the degree of metallic character of an element is a property called electropositivity which expresses the tendency of an element to form positive ions by losing electrons This property is exhibited in high e t degree by the heaviest elements of group I and dimini hes generally on proceeding to elements which lie above and to the right of this position Highly electropositive elements form oxide or hydroxides which are strong bases Potassium hydroxide (caustic potash) is a familiar example The nonmetals such as sulfur attract electrons and hence are termed electronegati e Solutions of the oxides of these elements in water yield acids Sulfur trioxide for example reacts with water to form sulfuric acid

Atomic volumes The volume occup ed by 1 gram atomic weight of an element in the olid st te is called its atomic volume If thi property is pl tted against atomic number the resultant urve exhib ts periodic maxima and minima the f mer be ng due princ pally to th metals of group I and the latter t th e m tal of g oup VIII

Other properties The p e e ling ctions aff rd only a limited illu tration of th imme se correla t ve power of the period c ar angement Other p op



F t o t p t t l l th el m t pl n d f ct l at m mbe

e t e wh ch ha bee h w t xhibit analogou tr d and pe t d t ea n l de o idat on pote t al he t f f matio f typ ompo nd electri al c d t ty melt g po nt, bo l g p nt o ic rad us zat n p tent al lect on affinity opti al spect um nd m gn t c beh i

Alth ugh s e m nt o has been m de of the la k of ag ement with espe t t det l of the pe od c rra g m nt it mu t n t be im g ned th t it br d yst mizat ns r m r d pe d nt pon on form f t bl th n an the

The pe od c t ble wa devel p d nd la gely perfe t d by Dm tri M nd l ev in th m d m e t th e tury a emp al c l t between th h m l p op rt f th el ment nd th ir at m w ghts In the l ght of modern kn wledge ch o l t t b exp t a n th m m c w ight d t rmi ed lm t enti ly by the m s of th at m n cl whi h pl ly an ign fi t le h mi l re t ns

W th few ex ept n h wev th s quence l l ment cco di g t t m w ight d t al w th th t c ord g t t m mbe Th l tte qu nt ty um r ally qual t th umbe f rt a u l a el tr ns th n utr l r u cha ged t m f a lem nt It the l tr n p t l ly th f the t m ed fr m the n cleu whi h de t rm n h m l beh v Th l us f atom a h te t r d r d n th e rly p rt f the nt tury r q th t equ f t m of r gula ly e ng at m n mb th r h ld be a p od n e the n mb r and typ of le t n n the o termo t lect on c h ll Th f rm the tr e b s f th p r d ti of th p pe t es of the l nts

Few y temiatic n in the h t ry of sc en e can r al the peri dic c n ept a a b oad rev l ti n of the rde of the phys l w rld In th rhythmic patt rn f th properties of the el ment the architectural unit of the uni er e n a pe t of their beha io cha ges i ap ic ou or wh lly o el w y Whatever new eleme ts may be d s o ered n the future it i ce ta n they w ll f nd a place n the pe od c sy tem c nf rming to its or der and e h biting the p per fam li l chara ter i tics S e ATOMIC STRUCTURE AND SPECTRA VA LENCE [B B CU]

Bibl g phy T Moeller I org nic Chemistry 1952

Periodicity in organisms

Chara te tic rhythm or ycl of l ving phenom e a Coll ti ely l i g organi m d play a b ad pe t m of p ri d le gths anging from such high f equen es s th of l rain waves (a comple of le tric l p tenti l rhythms i the b ain with ma y cy le per ond) and heart b at t the e veral y a ycl f abu da of rious p cies H w e pe d c ty in o gan m hall he e l arl t r ly t t p eted t i lude only l mited gr up of pe i d th r l t d to th n tural phy al ones f the earth namely days l na t des m nth and year The e p od ties mmo ly compri e im p ta t ad ptat of the o gani m to the n rm l fluctu t n f such h u e ironmental facto s ll m nati n temp r t re and the ocean tides These rhythm whi h in o ganisms in natur a e ll q ite pr c ely of the natural geophy c l f equenc es ha e e rta pec l in ommo wh h te d to s t them other

PERIODIC TABLE OF THE ELEMENTS

Ia	IIa	IIIb	IVb	Vb	VIb	VIIb	VIII	VIII	VIII	Ib	IIb	IIIa	IVa	Va	VIa	VIIa	0
1 H 1 0080																1 H 1 0080	2 He 4 003
3 Li 6 940	4 Be 9 013											5 B 10 82	6 C 12 011	7 N 14 008	8 O 16 000	9 F 19 00	10 Ne 20 183
11 Na 22 991	12 Mg 24 32											13 Al 26 98	14 Si 28 09	15 P 30 975	16 S 32 066	17 Cl 35.457	18 Ar 39 944
19 K 39 100	20 Ca 40 08	21 Sc 44 96	22 Ti 47 90	23 V 50 95	24 Cr 52 01	25 Mn 54 94	26 Fe 55 85	27 Co 58 94	28 Ni 58 71	29 Cu 63 54	30 Zn 65 38	31 Ga 69 72	32 Ge 72 60	33 As 74 92	34 Se 78 96	35 Br 79 916	36 Kr 83 80
37 Rb 85 48	38 Sr 87 63	39 Y 88 91	40 Zr 91 22	41 Nb 92 91	42 Mo 95 95	43 Tc (99)*	44 Ru 101 1	45 Rh 102 91	46 Pd 106 4	47 Ag 107880	48 Cd 112 41	49 In 114 82	50 Sn 118 70	51 Sb 121 76	52 Te 127 61	53 I 126 91	54 Xe 131 30
55 Cs 132 91	56 Ba 137 36	57 La 138 92	72 Hf 178.50	73 Ta 180 95	74 W 183.86	75 Re 186 22	76 Os 190 2	77 Ir 192 2	78 Pt 195 09	79 Au 197 0	80 Hg 200 61	81 Tl 204.39	82 Pb 207 21	83 Bi 208 99	84 Po 210	85 At (210)*	86 Rn 222
87 Fr (223)*	88 Ra 226 05	89 Ac 227 0															

LANTHANUM SERIES

58 Ce 140 13	59 Pr 140 91	60 Nd 144 27	61 Pm (147)*	62 Sm 150 35	63 Eu 152 0	64 Gd 157 26	65 Tb 158 93	66 Dy 162 51	67 Ho 164 94	68 Er 167 27	69 Tm 168 94	70 Yb 173 04	71 Lu 174 [illegible]

ACTINIUM SERIES

90 Th 232 05	91 Pa 231	92 U 238 07	93 Np (237)*	94 Pu (242)*	95 Am (243)*	96 Cm (247)*	97 Bk (249)*	98 Cf (251)*	99 Es (254)*	100 Fm (253)*	101 Md (256)*	102 No (253)*

*mass number of most st ble known isotope

there has been mu h debate as to the most suitable form of display A widely accepted modern ar rangement is presented in the accompanying table which is commonly referred to as a long table

Each element represented by its symbol occu pies a separate square of the table together with its atomic number and atomic weight The sequential arrangement is in the order of atomic number

The table di ides the elements into nine groups designated by numerical column headings and seven periods Seven of the nine groups are further divided into a and b categories the a elements of ten being cla ified as mai group and the b as sub group elements Two rows of elements (the lan thanide or rare earth series and the actinide series) which on the whole are be t classified as members of group IIIa occupy special positions outside the main body of the table as they cannot be included conveniently in their proper positions in periods six and seven

The following ections will serve to illustrate some of the correlati e features of the periodic ar rangement

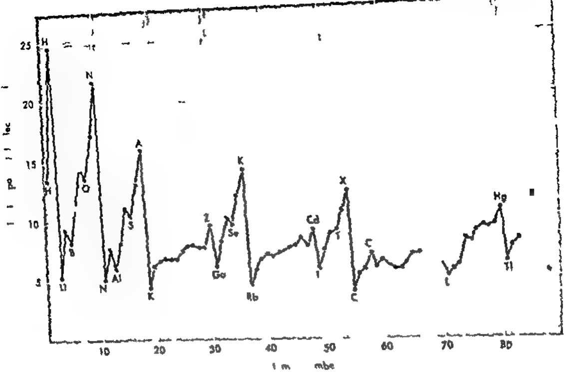
Valence In general elements in the same group display a similar valence which is numerically equal to the group number The rule holds most firmly for the main groups I through V less so for the subgroup elements and still less for the ele ments of groups VI VII and VIII Among these latter the group number valence is more readily achieved by the hea ier as c mpared with the lighter elements (Gr up 0 elements are distin guished by an al nost complete lack of chemical reactivity and hence show zero valence)

Metals and nonmetals The periodic table ef fects a natural division of the elements in the r ele mental or uncombined state into metals and non metal The nonmetals are confined to the lighter elements of groups IVa through VIIa Between the area occupied by the typically metallic elements and that occupied by the nonmetals there is a some what ill defined borderland of elements (germanium Ge arsenic As antimony Sb tellurium Te and polonium Po) whose properties are transitional be tween the metallic and nonmetallic elements

Acid base properties of the oxides of the ele ments Associated in a general way with the de gree of metallic character of an element is a prop erty called electropositivity which expresses the tendency of an element to form positi e ions by losing electrons This property is exhibited in high est degree by the heaviest elements of group I and d minishes generally on proceeding to elements which lie above and to the right of this position H ghly electropositive elements form oxides or hy droxides which are strong bases Potassium hy droxide (caustic potash) is a familiar example The nonmetals such as sulfur attract electrons and hence are termed electronegative Solutions of the oxides of these elements in water yield acids Sulfur trioxide for example reacts with water to form sulfuri acid

Atomic volumes The olume occupied by 1 gram at mic weight of an element in the s lid state is called its atomic olume If this property is plotted against atomic number the resultant curve exhibits period c maxima and mi ima the former being due principally to the metal of group I and the latter to the metals of gro p VIII

Other properties Th pre eding ect s affo d nly a limited illustrati n f the immen e correla ti e power of the pe dic arrang ment Other p op



F st t p t t l f the l m t pl tt d f t f t m mb

erti s wh h ha e b en hown to e hibit analogo s t nds nd pe iodicitt i lude ox d t potential l at f format on of type c mp unds ele tri al duct ty melt g po t, bo li g point io e di s i z tio p te t al ele tr n affin ty pt c l spect m nd magnetic b ha

Although some m nt n ha bee m de of the lack f agr m t w th e pect t d t ls *of th* periodi a a g ment it m st ot be m gi ed that it br d syst mi at ns a e mo d p nd nt po o e f rm f t bl than anoth er

The p od table wa d el ped and la g ly p f ted ly Dmitt s Me dele v n the m d n ne te nth c t y s a emp ri l c rrelati n betw en the hem c l p op rt e f th leme t a d the r atom c w ights In th l ght of mod rn kn wledge n s h rrelat n is t be exp ct d since th at m c w ght l term n d lm t tur ly by th m f th at m c u l s wh h play only a n g fic t r l i hemi l e ti

W th f w *except on* howeve th sequenc f el m nt cord g to tomi we ght is identic l w th th t di g t at m c n mb Th s l tt qua tity i m r ally eq l t th numbe of e t f r ele tr s in th n ut al cha g d t m f l me r It s th elect on part ul rly tho furth t r mo ed fr m th e ucle s wh ch de t rmi e l emi al b l Th l ws f atom a ch tect re d s red in the ea ly p rt of th p esent t ry q e th t t s q nc f t m f g l ly n r asing tom c n mb th re h uld be a per di recurren t the num b a d type f l ctr ns n the o t mo t lectr n h ll Th f rm the tru ha i f the p r d a t n f the prop rt of the leme ts

Few sy t mizat n i th e hi to y of c ence can ri l the period ncept a a broad r lati n of the orde of the phy ical w rld l the rhythmic p tte n f the pr p ties of the element the archit ctu r l un ts of the uni e e no aspect of th i beh or changes in capric ou r wholly no el way Whate er n w el ments may be di c ered in the f tu e it s c rta n th y will f nd a place in the per od c system conforming to its or der and xhib ting th proper fam lial ch aract r i ti s *Se* ATOMIC STRUCTURE AND SPECTRA VA LE CE (R B CU)

Bibli g aphy T Moelle I organ c *Chemistry* 1952

Periodicity in organisms

Chara t t c rhythms or y le of l ing phenom e a C lle ti ely li ng rgan ms d play a b ad sp ctr m f pe i d lengths ra ging from su h high f quen i s as th e of b a n wa s (a comple of el trical r tenti l rhythms in th e brain with ma y cycl s per ec nd) and heart b at to the e ral year cycle of abundance f ar o spec es H w e er per odi ti n rg n m h ll here l arbitrar ily i terp r d to cl d n ly a l mited gro ip f periods tho elated to the natur l phys al ones f the e rth n m l day l na tides months and y Th e pe d i e mmonly comp s im porta t adaptati n *f the* o g nism t the n rmal fl ctuat n of such ob iou e vir nme tal fa t s as illumin *t on* t mpe atu e and the an tides Th e rhythm wh h r org ms in natu e ar s ally q ite p ec s ly f th natural g ophy ical f e q nci s ha e certa n pecul ar p perties in c mmo whi h t d t t them apart from ther

PERIODIC TABLE OF THE ELEMENTS

Ia	IIa	IIIb	IVb	Vb	VIb	VIIb	VIII	VIII	VIII	Ib	IIb	IIIa	IVa	Va	VIa	VIIa	0
1 H 1 0080																1 H 1 0080	2 He 4 003
3 Li 6 940	4 Be 9 013											5 B 10 82	6 C 12 011	7 N 14 008	8 O 16 000	9 F 19 00	10 Ne 20 183
11 Na 22 991	12 Mg 24 32											13 Al 26 98	14 Si 28 09	15 P 30 975	16 S 32 066	17 Cl 35.457	18 Ar 39 944
19 K 39 100	20 Ca 40 08	21 Sc 44 96	22 Ti 47 90	23 V 50 95	24 Cr 52 01	25 Mn 54 94	26 Fe 55 85	27 Co 58 94	28 Ni 58 71	29 Cu 63 54	30 Zn 65 38	31 Ga 69 72	32 Ge 72 60	33 As 74 92	34 Se 78 96	35 Br 79 916	36 Kr 83 80
37 Rb 85 48	38 Sr 87 63	39 Y 88 91	40 Zr 91 22	41 Nb 92 91	42 Mo 95 95	43 Tc (99)*	44 Ru 101 1	45 Rh 102 91	46 Pd 106 4	47 Ag 107880	48 Cd 112 41	49 In 114 82	50 Sn 118 70	51 Sb 121 76	52 Te 127 61	53 I 126 91	54 Xe 131 30
55 Cs 132 91	56 Ba 137 36	57 La 138 92	72 Hf 178.50	73 Ta 180 95	74 W 183.86	75 Re 186 22	76 Os 190 2	77 Ir 192 2	78 Pt 195 09	79 Au 197 0	80 Hg 200 61	81 Tl 204 39	82 Pb 207 21	83 Bi 208 [illegible]	84 Po 210	85 At (210)*	86 Rn 222
87 Fr (223)*	88 Ra 226 05	89 Ac 227 0															

LANTHANUM SERIES

58 Ce 140 13	59 Pr 140 91	60 Nd 144 27	61 Pm (147)*	62 Sm 150 35	63 Eu 152 0	64 Gd 157 26	65 Tb 158 93	66 Dy 162 51	67 Ho 164 94	68 Er 167 27	69 Tm 168 94	70 Yb 173 04	71 Lu 174 99

ACTINIUM SERIES

90 Th 232 05	91 Pa 231	92 U 238 07	93 Np (237)*	94 Pu (242)*	95 Am (243)*	96 Cm (247)*	97 Bk (249)*	98 Cf (251)*	99 Es (254)*	100 Fm (253)*	101 Md (256)*	102 No (253)*

*mass numbe of most stable known isotope

there has been much debate as to the most suitable form of display A widely accepted modern arrangement is presented in the accompanying table which is commonly referred to as a long table

Each element represent d by its symbol occupies a separate square of the table together with its atomic number and atomic weight The sequential arrangement is in the order of atomic number

The table divides the elements into nine groups designated by numerical column headings and *seven periods Se en of the nine groups are further* divided into a and b categories the a elements of ten being classified as main group and the b as subgroup elements Two rows of elements (the lanthanide or rare earth series and the actinide series) which on the whole are best classified as members of group IIIa occupy special positions out ide the main body of the table as they cannot be included conveniently in their proper positions in periods six and seven

The following sections will serve to illustrate some of the correlative features of the periodic arrangement

Valence In general elements in the same group display a similar valence which is numerically *equal to the group number The rule holds most* firmly for the main groups I through V less so for the subgroup elements and still less for the elements of groups VI VII and VIII Among these latter the group number valence is more readily achieved by the heavier as compared with the lighter *elements* (Group 0 elements are distinguished by an almost complete lack of chemical reactivity and hence show zero valence)

Metals and nonmetals The period c table effects a natural division of the elements in their elemental or uncombined state into metals and nonmetals The nonmetals are confined to the lighter elements of groups IVa through VIIa Between the area occupied by the typically metallic elements and that occupied by the nonmetals there is a somewhat ill defined borderland of elements (germanium Ge ar enic As antimony Sb tellurium Te and polonium Po) whose properties are transitional between the metallic and nonmetallic elements

Acid base properties of the oxides of the elements *Associated in a general way with the degree of metallic character of an element is a property called electroposit ity which expresses the tendency of an element to form positive ions by losing electrons This property is exhibited in highest degree by the heaviest elements of group I and diminishes generally on proceeding to elements which lie abo and to the right of this position Highly electropositive elements form oxides or hydroxides which are strong bases Potassium hydroxide (caustic potash) is a familiar example The nonmetals such as sulfur attract electrons and hence are termed electronegative Solutions of the oxides of these elements in water yield acids Sulfur trioxide for example reacts with water to *form sulfuric acid*

Atomic volumes The volume occupied by 1 gram atomic weight of an element in the solid state is called its atomic volume If this property is *plotted against atomic number the re ultant curve* exhibits periodic max ma and minima the former being due principally to the metals of group I and the latter to the metals f group *VIII*

Other properties The preceding sections afford only a limited illustration of the imme e correla t ve power of the period c arrangement Other prop-

f m ll po bly eff ct e geophy cal pe ı dı m The the hyp the s th t the organ mı pe-r d d pe d up n a co t nu g e-pon e of the ga m t p rv g opl c l hythm It ha w b e f lly e tabl hed th t p r od m f all the n t al geophy ı al f eq ≡ cie a t lly d oc r l n th gs a re pon e t the r phy cal m nt e en under ≡ d t o s o t nt w tl e pect t ll the f t r forme ly n ıdered al le t ı fl e e them It h als bee p ıbl to ac nt q t ratı n lly f r all th u al b erved pr p tı s of phy ı l g e l rhythms ı term of h e o e u t m g t geth r w th kn wn p op-rt e f dapt e ph g f the rhythm by light d tempe at Th h ▪ th ı l c ı t f r th t a d ary tempe atu ≡ and dr ▪ ınd p nd n e of th hythm p ods [F A B]

B bl og phy F A B w J The rhyth ı t e of m l a d pla t *Am Sc nt st* 47(?) 14 168 1959 J E Ha ke D r al rl ythm ı the a m l k gd m *B ol Revs* 33 1 5 19 8 H M W bb d F A Brown Jr T m ng l ng cy l phy l g al rhythm *Phys ol Revs* 39(1) 127 161 1959

Perischoechinoidea

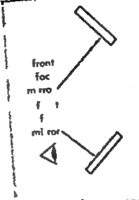
A b la f E h n de lacki g tab l ty th mb f l m f plate mp ı g th am b l ra nd te mb l c Th amb l ral l m ry fr m 2 to 20 th ı t mbul l from l t 14 Of the f ı lud d d thre e x l ely P l th the C d ıd l de b th P le d t t membe a d ▪ b bly t l t ll th rv ı g e h d S ▪ THRIO ID OID CIDA OID ECHI OCY TI TOIDA ECH NO EA P LA CHI OI A [H B F]

Periscope

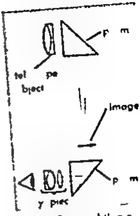
A pt l ı t m t that p rm t wı g al ng a d pl d o d fl ted x p d g a b ne with th w f m p t n wh h m y b n ble d ▪ P copes ge ı om plex ty fr m the sımple u t p we ta k pe ı c pe t the mpl m ltıelement bmarıne perı s p

Tank periscope This de e intend d t prot t the fr m bullet empl y a pair f plane pa all l fl ctı g faces (th r mır or ▪ m) arra g d a mou t tl at the p th f l ght th gh the tr ment fo m a crude l tte Z (F g 1) If p we greate th n ty a e de d r ıf th pe ope ıs t be d for ıghting t est l t le c pe c n be dded t the perı c p ther a a s mpl te lly ▪ ntaı ed sys-t m (Fıg 2) ▪ e t ly f nt of or behind the p ▪ t lf d r d The fl t g eleme t f th y t m wh ch a e r p ble f r deflect ı g the opt l s d p d t of th refract g (t le p) l m t wh ch p o de the opt l p we *S e* TELESCOPE

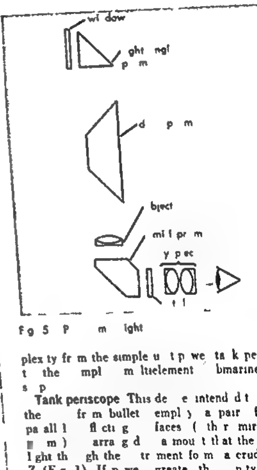
It l ▪ ble t g the two m r rs of a p p t ıght ngle to each th (F g 3) r



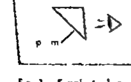
Fg 3 S mpl pe ope w th m o t ght n-gl Ob rv r iew i rt d im ge



F▪ 4 R ı ghti g p l-p w th vert g t le-c p Th im g l r t d



Fg 5 P m ight



Fg 1 S mpl t k p sc p w th ▪ ll l e-fl ct g rf

Fg 2 T k p p w th t t l t le-p

biological periodism and support the view that they are utilized very importantly as clocks and calendars to enable living things to live more harmoniously with their rhythmic physical environment *See* ECOLOGY

Examples of solar day (24-hour) rhythmic phenomena related to the rotation of the earth relative to the sun are the sleep movement of plant leaves and petals change in skin color of crabs emergence of fruitflies from pupal case wakefulness and spontaneous activity of animals body temperature hormone titers in the blood and susceptibility to drugs and toxic agents Lunar day (24 8 hour) rhythms related to the rotation of the earth relative to the moon are characteristic of many activities of animals dwelling on the seashores subjected continuously to the moon dominated ocean tide The rhythmic daily and tidal patterns of organismic change are adjusted to the physical environmental cycles so as to be of optimal survival value The synodic month of 29 5 days is the period between two successive synchronizations of solar and lunar noon or the average period separating two consecutive new moons Of this average period are for example the reproductive cycles of many marine animals and plants and the human menstrual period Annual periodicities in organisms are most evident at latitudes distant from the Equator but strangely enough they may also occur in organisms in the annual constancy of equatorial region Familiar examples of annual rhythms are those of reproduction in animals and of growth flowering and fruiting in plants *See* BODY RHYTHM ESTRUS GESTATION PERIOD PLANT PHYSIOLOGY

Persistence of the rhythms Although in the natural environment the observed cycles clearly depend in good measure upon organismic responses to the cyclic patterns of such factors as light temperature and the ocean tide it is commonly found that when the organisms are removed from their habitat and placed in conditions constant with respect to these factors the organism not only may continue to exhibit the same rhythmic fluctuations with closely the same periods but may retain in the daily or tidal cycles even detailed characteristics of the environmentally impressed adaptive pattern The organism therefore possesses some means for timing the cycle periods which does not depend upon the rhythm of the obvious environmental factors which normally determine the form of pattern of the cyclic fluctuation Furthermore this whole pattern of the persistently recurring cycles can be abruptly shifted to bear any arbitrarily selected phase relationship to the natural external day night cycles by appropriately adjusting the time of day of occurrence of change in such factors as light or temperature in artificially administered 24-hour cycles of these factors Once shifted the cycles may persist in the constant laboratory conditions with the newly impressed relationships relative to the time of day by the clock It

light and temperature the phases of the rec
fluctuations may display a spontaneous small
shift to yield observed regular periods whi
longer or shorter than the natural ones

The rhythms persisting in constant cond
are timed by a mechanism well adapted for
ing temporal precision If timing were depe
exclusively on a clock of a conventional met
type the periods would shorten at higher ten
tures and lengthen at lower ones Drugs mod
metabolic rate would similarly give timing
curacies However numerous experiment
shown the organismic timer to be essentially
pendent of such alterations in metabolic
Color change cycles with accurate solar and
periods continue over a 20C temperature ra
fiddler crabs in constant conditions Plants
tinue to show daily sleep movements of their l
or other rhythmic activities with relatively
change in period although they may be subj
to wide ranges of constant temperatures or f
ing application of metabolic depressants Seed
hibit an annual rhythm of germinating cap
when stored in constant conditions wheth
−22 C or +45 C or even in the continuous
ence of toxic agents or absence of oxygen
CHROMATOPHORE PROTECTIVE COLORATION

There is substantial evidence that certain
sistent solar day and lunar day rhythms com
timing systems enabling animals such as bird
arthropods which navigate using sun or moo
correct continuously for the earth s rotation i
der to maintain straight compass directions T
are also reasons to believe that solar day rhy
serve as timers underlying the well known o
ismic response to seasonal changes in day len
photoperiod *See* PHOTOPERIODISM IN PLANTS

Mechanism of persistent rhythms From
preceding it is evident on the one hand tha
clocks underlying organismic periodicities
remarkably stable and accurate in period le
and yet on the other hand that the cyclic patt
of change are quite labile and plastic as the or
isms adaptively use these basic clocks to ad
themselves readily to changing demands of the
ironment In brief the rhythms comprise o
the most remarkable illustration of organi
adaptation to their physical environment

Two basic hypotheses exist for the nature of
organismic timing system One of these is th t
organism possesses quite independently f
physical environment natural period of bi ch
ical oscillation matching closely all the natu
ge physical frequencies The periods are bel
to have reached their present length with th
of natural election and now to be p ed n gen
cally The major difficulty f this hyp the
problem of concei g an organismic illa
with such long periods a th physical
of the extra rd nary stability of peri d
for the existence of ch a fully aut n m u ch
system must await demonstration of p r i te

Fg 1 The odd t d me o fo t f th p s d tyl Th l ft h d f t f M ry h pp j t l t M hors h w g th s g l (hod d) with ts s gf p ll yl k j t (Aft H O born 1918)

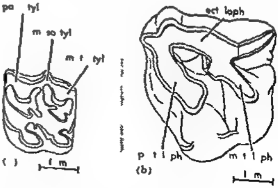
p dly ach ng p ak f d er ty by l te Eo ne t m Th s lat e olut n po bly o di t o ed by r s g rt d tyl ompetit n l es dec eas ng di ty nd empha n c ta n of th b tter ad pted l ne S ARTIC DACTYLA FOS SILS Co DYLARTH s FVOLUTIO ORG NIC

Th de h cter d by emphas on the th d d git the p s sp l we ht b a er the first s l y nd th fifth lly suppre ed w th a) ll te al d ct n of the ec nd a d f th d g t s ld ng t t a t a d m n d tyl d t Th t agal ha s gle p ll yl ke j nt t lat ng w th th tib (F g 1) Th t sal art l ti n flat th fem r h th d t cha te Th f the ch k teth t d t be j d by dg (l phodo t) d th p molars b e me p g e lv m l f rm

Two b d ha e been e gn ed th H p p m rph n l d ng the ho s h n l ke b t the e d th p ulh r l wed ch h o th nd th Ce t m rpha s l d g th t p r d rhi oce B th ub d d e ged from a mm b t s) t k w a try n the l t P l Aft th ly E th l t o p d d l ng ep te l nes Th h ppom rph f d th dev l pme t of W h p d t l ph d st ng st l th pp che k te th (F g 2a) h l th e at m phs et d im pl l a t l ph a d e p u styl (Fig 2b) d h n e r s ev l ed h gh w d teeth th l te T t ry appa e tly respon e to the pread of gra land en ironments at tl at t me

Hippomorpha Horses (N rth America and Eu rope) and the r cl all es the palaeotheres (Eu rope) appeared in the early Eocene while tl eir c ntemporari s the brontotheres eem t ha e l een restricted t N rth America The rapid evoluti n of the brontotl eres was remarkable f r by late Eo cene time this grou p had reached it greatest di versity producing some of the large t land mam mals tl en kn wn N m r h r es re cl ed Europe unt l the M ocen but br ntothere apparently reached both Europ and A ia by late Foce time and linge ed there until th middle Ol g cen Fx ti ct on of the bront theres l ad already taken place in North Ameri a by tl e cl e of th early Ol gocen The chali oth res fir t appeared in North Am rica a d Fur s a in the late Foc ne l ut did n t urv e the m ddl M ocene in North Amer ica. They apparently rea hed Africa in th latest Ce zo c and urvived there sometime aft r th eir e tinct o in the Plocen cf Fura ia The main str am f h volut on learly t k place i North Amer ca fr m which Mi cene Pliore and Pl i t c ne i a io s of E ra ia were laun hed So th Amer ca was in aded m r tha once by h r es and tapirs in the late C n z

Ceratomorpha Primit e tapiro d we e mmon in the E c ne f Eura nd North Am rica k it the modern family d d not enter the record until Oligo en time Alth ugh they inhab ted the North ern Hem phe e u t l the cl e of tl e Pl istoce e tap rs urv e today only i the Old a d New W rld t op s Th rh nocero s f rst appeared in th early Eocene f No th America and l y Ol gocene t me i habited the wh le f the Northern H mi sphere At that time th y s m to ha e att ined th ir max m m d elopment, producing such g ant as *Pa ace athe um* the large t terre trial mammal known By Miocene time the Focene l nes



Fg 2 Th fi t upp m la f e t t pe da tyl ( ) A l te M h pp m ph th hors *M ry h pp* *t t (l m H* Osbo 1918) (b) A ly M at m h th h D *the*

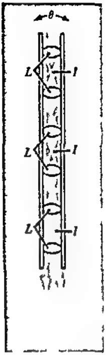


Fig 6 Periscopic relay train showing lenses L, inversions I, and angle of view θ

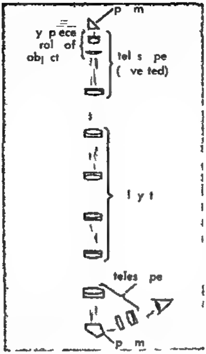


Fig 7 Submarine periscope: a pair of facing telescopes with a relay train between

which case the observer views an inverted image with his back to the direction from which light enters the instrument By adding an inverting (astronomical type) telescope to this system (Fig 4) the image is reinverted *See* TELESCOPE ASTRONOMICAL

Periscopes of this type cannot be used for scanning the horizon by rotating the upper mirror because of the image rotation which accompanies such movement In the panoramic sight (Fig 5) this difficulty is overcome by providing the system with a dove prism which rotates at half the angular speed of the right angle prism through the action of a differential gear linkage The combined inversions of the dove prism and the amici prism at the bottom completely compensate for those of the telescope system while the relative motions of the right angle prism and the dove prism maintain the image erect during scanning *See* PRISM OPTICAL

Submarine periscope In this device it is necessary to employ a telescope system having a wide field of view and uniform illumination across the field which can be fitted into a long narrow tube whose length to diameter ratio may be 50 or greater This is achieved by utilizing a plurality of lenses so spaced along the length of the tube as to cause the incoming principal rays from the edge of the field to be deviated from side to side within the tube In general the greater the number of lenses the wider the field of view One example of the periscopic relay train is shown in Fig 6 and employs six lenses with three inversions The typical submarine periscope (Fig 7) may be considered to be a pair of telescopes facing each other with such a relay train between The usual magnification of submarine periscopes is 6 although some U S Navy periscopes have dual magnifications of 6 and 1 5 the latter being achieved by inserting an inverted Galilean telescope into the optical path before the top objective

The submarine periscope can be provided with a built in rangefinder for fire control purpose A conventional coincidence or split field type of rangefinder may be attached either vertically or horizontally to the upper end of the periscope the objective of which receives an image from each of the entrance windows of the rangefinder *See* RANGEFINDER OPTICAL SUBMARINE

Other types Various modifications of the basic optical systems described here are employed as viewing periscopes in military aircraft and as viewing devices in particle accelerators and nuclear reactors The cystoscope and endoscope are slender sometimes mechanically flexible periscopes used for visual examination and photography of body cavities inaccessible to direct observation

[E K K]

Bibliography C H v Hofe *Fernoptik* 1941 D H Jacobs *Fundamentals of Optical Engineering* 1943 A Konig *Die Fernrohre und Entfernungsmesser* 1937 L C Martin *Technical Optics* vol 2 1950

Perissodactyla

An order of hoofed mammals in which the axis of the foot passes through the middle toe often called the odd toed ungulates The order includes the horses tapirs rhinoceroses and their extinct relatives Perissodactyls first appeared in the early Eocene reached the height of their evolutionary *history in the Oligocene when they were the domi*nant ungulates in most of the world and have been on the decline ever since The order is represented by two principal evolutionary lines The Hippomorpha include the horses and three other groups now extinct the paleotheres titanotheres and chalicotheres The Ceratomorpha include the tapirs rhinoceroses and several families that became extinct in the late Eocene and Oligocene the isectolophids lophiodontids helaletids hyrachyids hyracodontids and amynodonts *See* EUTHERIA PERISSODACTYLA FOSSILS [D D D]

Perissodactyla fossils

The odd toed ungulates hoofed herbivores represented today by the horse tapir and rhinoceros families have a fossil record that includes nine additional families This record forms one of the most completely known chapters in the history of the Mammalia Horses in particular provide a record that in richness of detail has produced the most compelling paleontological evidence for evolution as a natural process The origin of the perissodactyls however is still obscure although it is clear that the Condylarthra provide ideal structural antecedent Perissodactyls first appear in the early Eocene of North America and Europe and evolve

t the gr ıp of mob le pern ıchs Its pecie are a o tated w th a w de ar ety f ın ertebrat and t b ate hosts wh ch ıts actı ns range f om th s of a harmle s c mm ns l to a pathogenic pa s t Se HOLOTRICHA [J O C.]

Periwinkle

A name appl ed t v u l nd fre h water and m e n l but p op rly de tıng th small ma rın n ıl *Littorın litt* the typı al pe ıes f the fam ly Litt r da cla s Ga t opods phylum Moll a

Th perıw nkl s a at e of Fur pe whe e ıt ı a stapl food num l Thou nds f tons a e old annu lly ın Engla d l n It has been ntr d ed at a us po nts along the Atlant c Co st of N th *Am ı a nd ı o* ab nd nt from Lab ador so thw d to Cape May N w Jer ey Th r ıs a l mited f t for f od n the United State

Thı an mal al o of ome ımp rt n e a a fi h food and ı met me u ed for fi h b ıt It h s l e me espec ally ab d t along the Ma e coa t h r l rg umbe s r po d by l w tide ks wh rv e weeds ma h g a r ın d t h and t de pool

This a l may gr w to l ın ın l gth and has a a ı u ly olored oughened sh ll b o d and r ded w th 6 o 7 whorl nd a a ute p x Th tsıd f the h ll ı glos nd ıs ma ked with d k ba d n a backgr und of y ll w brown ol e ed r bl ck The n ıde f th hell a e f om wh te t b wn Th pe wı kl foot dı v ded long tud nally that t sw ng f m d ı d ıt m es Its h d p ject from the hell nd ı q pped w th two e l te ta l with ye t th ır b e The hell ı qu pped with a h r y pe l m

Oth f th ge *L ıt ına* all m m nly lled p w nkl c r n ll coa t f the Lnı d St t

In f sh w t r ny sm ll ab nda t sn ıl a l kely t be lled p wınkl The n m ıs l n a pt d mm n me f r a pl nt Vı c m o wh h g w wid ly a gro d co er See GAS R ODA SNAIL [J D B]

Perlite

A n t al gla s w tl l da t phe al n l t ck wh h tt b e k nt m ll p rl lık m pebble us lly les than a e t m te s It mm ly g a o g een w th a pe l l t r du t fle t o s f om the th a r film f rm d l ng th p l tı f a tu P rlıt k n t c t ly nf ned to p l t but ppe p d all n m t atu al gla e Gl s f rn d by ap d e l ng f m lten r k m t l (la a) nd th e ck r g n ally bel ev d t de l p by e t a t n du ı o l g Th w t r t t f p l t s c mm ly 3–4 by w ght M t of th m ı t b l eved t h b n b th d by the gl f m t r und ng Som tud s ggest th t p rlıt k m y fo m n p t tl h d ı

Under heat treatment (about 1500–2000 F) tl e c nta ned moı ture f rm tıny steam bul bles ın the soft ned gla and the perl t ı "p pped r ex ploded t ughly 15 or 20 tıme rıgınal v l ume Th the material ıs excellent for lıgl t weight aggreg te m latı n fıll r and f lter N tal le dep ıts are w rk d ın Cal f n a and New Me ıc Perlıte m y o n tıtıte major portı n of la a flows r occ ır ın mall ıntru n (dikes) Se IGNEOUS ROCKS LAVA VOLCANIC GLASS [C A CA]

Permafrost

Pe enn lly froze gr ı nd occurrı g where er tl e temperat re rem ı s l l w 0 C f everal year whether th ground ıs actı ally c nsolidated by ıc r not a d regardle l the nature of the r ck and s ıl particles of whı h the earth ı c mpo ed Per hap of the t tal lan l are f tl e earth n taıns permafr t ıt s c nt nuou ın th polar re g ons nd l ecome dı o t nu ı and p r dıc toward the equat r Du ıng gl cıal tıme perma fro t extend d hundred of mıl oul f ıt pre ent lım ts ın the Northern Hem phe e

Permafr t ı thicke t ın that part f the n tı u z e that ha not been glac ated The ma ımum r ported thıckn about 620 m ı at Nordv k ı n rth rn S l rı A erag ma mım thı kne es ar 275–400 m n north rn Ala ka a d 300– 00 m ın n rthern S b rı l Ala k the gen ral range f thıckne s ın the dı c nt nu u zo e ı 50–150 m and ı the sp rad c z ne le tl 30 m S GLACIAL EPOCH

Tempe at re of pe m fr st at the depth of no an ual ch ng abo t 10–30 m generally ıs b low −5 C n the ont n ou zone l etween −1 and −5 C ın the d nt nu us zo and abo e −1 C ın the p d z ne Temp atu e grad ent vary hor z nt lly nd vert cally fr m place to place and f m t me t tıme

I e s on of the m st ımp rt nt components f permafr t being esp cı lly mpo ta t where ıt ce ds pore p Phy ıc l pr pert s of perma fro t ary wid ly f m tho e f ıce t th e f nor mal k types The old ers that ıs th n m ber of c l rees eq d t brı g the mat al t the melt ng poı t a d melt the c taın d ıce ıs det rm ed larg ly l y m ıst re cont t Ice occur nd d al ystal a gı g n s z fr m less tha 0 1 nm to at l a t 70 cm n d m t r Aggr gates f e y tals e c mm d ke laye s r eg l r ma e and wedge The e f rms re derı d ı ma y ways Ice wedg charact e fin gra n d ed m t ntı ı p rm fro t and ı ı t ut l p lygo M c o op c t dy f th n t on l e w dge er l mpl x t uctur f whı h fl t a umul t o f ı ın ea l c n t a t on cr ck

Pe m f t de l p t day wher th n t h t balan f th f e f th a th ı ne at for e l ye r Much p rmafr t w s f m d th a d f y go but m ın q l h ıum with pr nt l t Permafro t l n mate m t gro nd w t m ı m nt pr erve ıc e aın

had become extinct and only the modern family remained. At that time the rhinos had reached Africa and by the close of the Pleistocene they were restricted to that continent and southeast Asia, having vacated their North American birthplace as early as the middle Pliocene. [R H T]

Peritoneum

The membranous lining of the abdominal cavity, composed mainly of flattened epithelial cells that produce a small amount of watery or serous fluid. In the embryo the interior body wall is covered with this membrane, which continues over the developing tubular viscera so that they are suspended and supported by the reflected peritoneum, principally from the posterior body wall. *See* EPITHELIUM.

As the organs develop, enlarge, and assume their adult form and arrangement, the supporting peritoneum becomes modified, some being lost and other portions becoming thickened, twisted, or otherwise adapting to normal growth. After development is completed, those portions which line the interior body wall are called the parietal peritoneum, and the supporting sheets are known collectively as mesentery, although many areas have received specific names. The remaining peritoneum, which covers most of the organs, is called the visceral peritoneum, and this forms the outer layer, or serosa, of the walls of portions of the gastrointestinal tract.

The remaining space, containing a small amount of fluid, between the serosa and the parietal peritoneum is the remnant of the coelom, or body cavity.

In lower vertebrates there is less complexity of development of the viscera, so that the peritoneum in fishes, for example, remains a fairly straight suspensory structure which supports the tubular digestive tract and continues around the body cavity to line the inner wall. [E G S T]

Peritonitis

Inflammation of the peritoneum, the serous membrane which lines the abdominal cavity and surrounds most of the abdominal organs. The condition may be caused by infectious organisms or foreign substances introduced into the abdominal cavity. The small amount of serous fluid normally present as a lubricant acts as an excellent culture medium for bacterial growth and also as a means of spreading invading material. The source of such substances or organisms is commonly a gastrointestinal inflammation, especially if perforation has occurred. Appendicitis, peptic ulcer, cancer of the bowel, gallbladder disease, and dysentery are common sources of infection that may produce peritonitis, as well as blood-borne forms of tuberculosis and pneumonia.

Infection may also stem from spread of bacterial organisms from the female organs, the kidneys, and the pancreas. Each form of peritonitis may show both common and specific features.

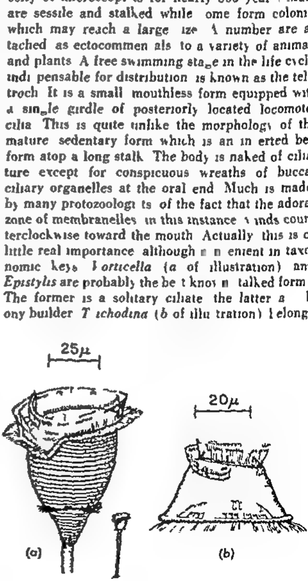
Contamination of the abdominal cavity may occur from penetration of the abdominal wall during an accident or following a wound. Bile, blood, or fluid from a ruptured abdominal cyst or ectopic pregnancy may also induce a peritoneal inflammation.

Where peritonitis occurs, the normally glistening peritoneum becomes dull, the blood vessels engorge, and a fibrin-containing exudate is produced, which may later lead to adhesions. A tendency for localization is apparent, with loops of intestine or other organs forming pockets of inflammation.

The clinical course is quite variable, depending on the agent involved, the type and severity of reaction, and concomitant disease. *See* AMEBIASIS; BACILLARY DYSENTERY; GALLBLADDER; PEPTIC ULCER; PNEUMONIA; PREGNANCY, DISORDERS OF; TUBERCULOSIS. [E G S T]

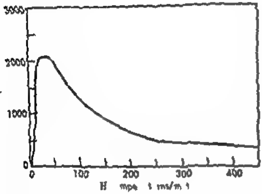
Peritrichida

An order of the Holotricha composed of a group of unusual looking ciliates that has excited the curiosity of microscopists for nearly 300 years. Many are sessile and stalked, while some form colonies which may reach a large size. A number are attached as ectocommensals to a variety of animals and plants. A free-swimming stage in the life cycle indispensable for distribution is known as the telotroch. It is a small, mouthless form equipped with a single girdle of posteriorly located locomotor cilia. This is quite unlike the morphology of the mature sedentary form, which is an inverted bell form atop a long stalk. The body is naked of ciliature except for conspicuous wreaths of buccal ciliary organelles at the oral end. Much is made by many protozoologists of the fact that the adoral zone of membranelles in this instance winds counterclockwise toward the mouth. Actually this is of little real importance, although convenient in taxonomic keys. *Vorticella* (*a* of illustration) and *Epistylis* are probably the best known stalked forms. The former is a solitary ciliate, the latter a colony builder. *Trichodina* (*b* of illustration) belongs



Peritrichida. (a) Vorticella, a stalked peritrich. (b) Trichodina.

M terial may be clas ifi d in te ms of their rel ti e pe m ab lit e D amagn t c mater als h ve alu s f µ a l ttl l th n nty param gnetic mat ls ha e µ a l ttl greater than nity Fer rom t m terials a e th e th t have relati e p me b lit d r bly gr ater than unity wh h re i ble depe d g up the v l e f H nd th pre u ma net c h to y F r some ferro mag et c m teri l the m imum l e f µ may b n the th u ands (F 2) S e MAGNETIC MATE RIALS e al o DIAMAGNETI M FERROMAGNETISM P R AG ETIS



Fg 2 P m b lty f w ght fu r f m g t f ld r gth

Permeability measurement The t o d l l ma b ed t m e the perm bil ty of a ma t ral f tl m te l s ed a th t f th ng Su h i g all d Rowl nd r ng A s o d m ll l ll d a h l w d a nd p rt f th nd nne t d t ball st gal a m t (C L NOR FTER SEARCH COIL) Wh the u r t th r g er ed th e is a cha ge i fl x f 2Φ The defl t f the gal n m t gi a m a f Φ Th l e f B th n f nd l y d d g Φ by the o s t al a f th g Th) f H i f d by the u e f th r l t H = NI l and µ i mr t d The R wl d i g ed f tl m m t h e e n th the fl x all m t al th t s be g t ted thu th r o pol and the m g t ten ty H s th t d e t th u e t l ne Othe dev (me s rem t f pe m b lity a e lled p rm m t s They e ba ed th me p n ipl a the R wl d r g b t ll w m r ap d a d n e t pe at o S INDUCTION MAGNETIC MA ETIC FIEL [K M] *B bl g phy* W C M ch l *El ct l Mea u m nt* 3d d 1957 F W Se r *Prin ipl of Ph* 1 2 1951

Permian

A p d f g l g c t me a d a c r p nd g ys t m f ock th yo g t th P l o Er It w s d fined by R I Mu h n 1841 nd wa b ed p th P m n B n t f th Ur l A p ent tly nd r t od t clud fi e t g as d t d F g 1 S PAL O OIC *lso* STR TIGR HIC S E LA URE

The Russian Permian The ba e of the Permian System was orig nally drawn at the ba e of tl e K gurian A P Karp n ky (1889) lat r demon trated the Permian age of the underlying detrital format ons on the ba i of ammonit s and more recently So iet geol gi t ha e sh wn that tl e l m t nes of the Ufa Plateau are an eq i alent f cies Th pr se t off cial a age of the Geol gical Survey f the Soviet Un n is the cl se a sh wn in F g 1 The upper boundary of the Permian Sy tem fall with n the Tatari tage of the older litera ture i clud ng only the lower two of fi e faun l z nes

The detr tal facie of the Sakmarian and Artin kan tage is c nfin d to the flank f the Urals th calcareou fa ie well di played in tl e Ufa Plate u extend far to the west o r the R ian Platfo m and comes to tl e urfa at th Samara Bend of the V lg nea K il y hev (Fig 2)

Duri the Ku gurian age the ea withdrew into the geosyn l ne where n der extremely arid c ndi tio s ast dep ts of anhyd ite an l h lite were precipitated l the v cin ty of Sol kam k the e d po it in l de imp rta t len es of the pota h alt syl ite and ca nall te Kungur an faunas are very re t cted and in lude no fu ulines

The Kaza i n Stag is repr nted l y b rren red and tone n th flank f the Ural but g ade w tward th ough b a k l water depo t i to ma ri e l me tone nd cal eo s hale at K za The li nge f fac e with de p ntert ngu g *l m tine* and nonma ne unit is w ll di play d i tl e bl ffs of th Kama Ri er The m st e fa nas incl de bry zoan and bra l iop ds but fu ul n s a d am mon te a e absent

PRE CAMBRIAN		PALEOZOIC							MESOZOIC			CENOZOIC	
						CARBON-IFEROUS							
ARCHEOZOIC (EARLY PRECAMBRIAN)	PROTEROZOIC (LATE PRECAMBRIAN)	CAMBRIAN	ORDOVICIAN	SILURIAN	DEVONIAN	MI PP	P yl	PERMIAN	TRIASSIC	JURASSIC	CRETACEOUS	TERTIARY	QUATERNARY

The T t rian redl eds a e w dely spread across th Ru n Platf rm whe they h yi lded fo l ert b t and pl nts b t no m r n qu v l t are k own th Pe m an Bas n

The American *Permian* F f ably the f nest Per m n sect k wn i that in the b n f T a F o T xas a d th te n N w Me ico The the Perm an q n rea l e tl ck ss of more than 12 000 ft Th ocks of th lower 500 ft are f ma e o igi d re h ghly fos ilifero s Al though a few fo l f om this reg on we e de c ib d i 1858 th occurr nce ema ned i tually kn wn until 1909 whe G H G rty p bl hed l is m nograph *The Gu d l pe n F a* Int n i tudy foll wed th d y f o l in th r gi n

restricts or inhibits plant growth and aids frost action it is also one of the most important factors in engineering problems in the polar regions *See* FROST ACTION MASS WASTING SOLIFLUCTION

[R F B]

Bibliography R F Black Permafrost—A review *Bull Geol Soc Am* 65 839–856 1954 S W Muller *Permafrost* USGS and U S Corps of Engineers Strategic engineering study Spec Rept 62 1945 (reprint 1947)

Permalloy

An alloy of iron and nickel with or without small or moderate additions of other elements Permalloy is of scientific and technical interest because it has unusually high magnetic permeability

The nickel content varies from about 40 to 80% The most commonly added element is molybdenum (4–5%) but similar amounts of chromium and copper are also used these increase both the permeability and the resistivity The highest permeability is obtained in Supermalloy in which are combined the beneficial effects of alloy addition (5% Mo) high purity (aided by heat treatment in pure hydrogen at 1300 C) and optimum cooling rate (1–5C /min) through the critical temperature of ordering (about 500 C)

The binary alloys containing from 50 to 80% nickel are susceptible to magnetic anneal that is their magnetic properties are drastically changed if they are cooled from about 600 to 400 C in the presence of a magnetic field of a few oersteds The maximum permeability is thereby raised and the hysteresis loop becomes rectangular in form

For the compositions and properties of the most used permalloys *see* MAGNETIC MATERIALS *see also* PERMEABILITY MAGNETIC [R M BO]

Permanganate

The deep purple anion MnO_4 which is derived from permanganic acid HMnO Although the parent acid is stable only in dilute aqueous solution the salts are well characterized The permanganates resemble the perchlorates in their oxidizing properties and solubility of both the heavy metal and alkaline earth metal salts

Potassium permanganate the most common permanganate is produced from a mixture of potassium hydroxide and manganese dioxide which has been oxidized by potassium chlorate chlorine or ozone Permanganates are used as disinfectants oxidizing agents wood preservatives and bleaching agents *See* MANGANESE COMPOUND OXIDIZING AGENT [E E WR]

Permeability magnetic

A factor characteristic of a material that is proportional to the magnetic flux density (magnetic induction) B produced in the material by a magnetic field divided by the intensity of the field H Permeability is usually represented by the Greek letter μ

Absolute permeability Consider a solenoid that has been bent into a circular form so that the ends

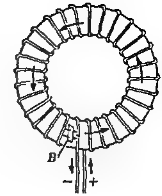


Fig 1 A solenoid wound in the form of a toroid

are joined together This winding is called a toroid (Fig 1) For a closely wound toroid almost all the flux is in the interior The intensity of the magnetic field inside the toroid is

$$H = \frac{NI}{l}$$

where l is the mean circumference of the toroid and I is the current in the toroid coil *See* MAGNETIC FIELD

The flux density B within the toroid is found from Ampere s law to be

$$B_0 = \mu_0 \frac{NI}{l}$$

if the toroid is in empty space (*see* AMPERE S LAW) Then

$$\mu_0 = \frac{B_0}{H}$$

If a medium takes the place of the empty space within the toroid the value of B changes for the same value of H The ratio of B to H is called the absolute permeability of the medium

$$\mu = \frac{B}{H}$$

Since the mks unit of B is the weber per square meter and the corresponding unit of H is the ampere per meter the mks unit of permeability is the weber per ampere meter A second unit is the henry per meter That these two units are equivalent is seen from the relationship $L = N\Phi/I$ Since the inductance L is in henrys when the flux Φ is in webers and I is in amperes the henry is a weber per ampere Thus a henry per meter is the same as a weber per ampere meter *See* INDUCTANCE

Relative permeability It is convenient to define another quantity called the relative permeability μ_r as the ratio of the permeability μ of the material to the permeability μ_0 of empty space

$$\mu_r = \frac{\mu}{\mu_0}$$

Relative permeability is a pure number and independent of the system of units used The permeability of free space has the numerical value of $4\pi \times 10^{-7}$ henry per meter *See* ELECTRICAL UNITS

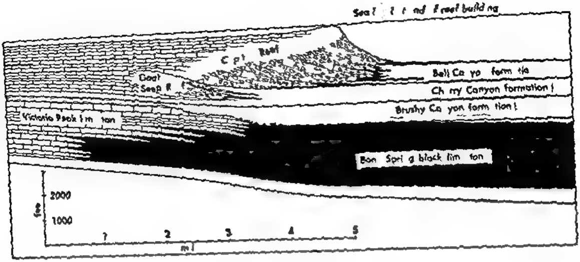


Fig 4 S t th C p t R f C mpl (Aft P B K g)

t t th t ng e f al aren te Th ba k re f d p t e c lc re u lo d st nces ry g f m l t 5 m le The d p t th n gr de r p dly into gyp tfe h le d hydrit G ay a ds m t rto gu f m the l dwa d ma g n f the la g o Farthe b k th a d pas t to edbeds

O h t me Fi ally d g Ocho t me th m wat w thd w nt ely t t the b s s d d te ly a d c d t be m d sd e wh ch rm d po t of a hyd ite a d l t f h l t w e p ec p t t d I t rb dded w th the s lt t the te f th D l w e Ba e ev l l a f p t h s lts—sylvite, arn ll t d p lyh l t

P b bly th r g e t e f mplex is well p d ha be t n ely t d ed that f Cap t Reef Ce z fa lung upl lted the G d l p M t E t mmed tely to th west t p d d th Salt Fl t g ben Thu gr t n t l e t r the f comple w s e p s d Th Cap t R f w se t lly l nd l my b k al g th m g l th pl tf rm a d m h l th b t m y h be p e ip t ted b o h m lly M h f t t sp gly f l f s b t pl t fill d w th fo l wh h l t lly m l ted a typ l eel me t

F m s dy l deep well e th W t T a f rm t e k w t e t d tward der th St k d Pl t t l T a wh they r pp t th f c Th th e outc p t t h th twa d cr Okl h m nd K

Th W ll mp q l m l g ly of m g t al T d K s M d t pe ted w ll t Le d n t me n t l T b t k ry l ge s lt d po t t th W ll gt h le) f ll w d by a th k db d q e By Gu d l p t m m t f th d p t te t l T w n m s e dded w th ev l th m d l t t t m g l m th we t l Okl h m ll b t the) p t f th Wolf mp the edb d t b l th lo l fl f the Okl h m m t

Other regions P rmi n depo it a e thick a d w despre d in many th r pa ts *of the world* par ticula ly in So th Africa Aust alia Ind a China I doch a and Japan and probably al o i So th *Ame ca*

South Africa Th Permia of South Africa i ent ly no me tne and is n table *for its exten* i m gl i l dep ts as well as its *f al reptiles* Here the sect on beg n with the wide pread Dwyka t l l te f ll wed by the Ecca tt a d the l w r part of th B auf rt *ert s* The e three co tit te the l we part of the K oo System The Dwyka tillit is d c ssed bel w nd r P rm an glaci tio

Both the Ecc and Be ufo t se es a e ry thick in the ld g sy cl which par lleled the south e co t of Cape Col y b t e h th s n rthw rd and m ds w dely o the outhern part of Af *c The Ecca* ser es co sts f d k shales a d s d tones a d clud th Coal Meas res of Af a The B aufo t e was spread ver the Ecc ries fter int rval f ero lt d ffers from th E a s ries n ha t g t terb dded y ll w t h and t es me m mbe s f red h le and d s t ct rept l an f s

Aust l The A tralian t nent was l gely em gent d g *Perm a time* e cept f r a eries f ma g l ba s l g both the we tern a d e st n c t The e b s b ded depend ntly alth gh the Pe m d p t th k st is im m ble t t eat th m d q t ly w th th limits f thi t cl Th *m t s* gn fi t f ct th t th Perm n be n S th Af i begi w th w d sp d gl al d p t In the C c y e B f rthw st Au trali th l d t llit wh h ep e ts g n d mora t g n n ld e n rfa e In m t of we t rn A t al a h w the glacial dep t ppe r as b ld r bed te ca l t d m t e d to e o shale s l ndica t n th t th ll uld we e d *opped f om fl* ti g

I the west rn b s te bedd d ma i e e the Ly d tone fi the amm nit *lf tal g a* j kso wh ch dat the d p s t S km n ly Arti k n Alt d p ti n

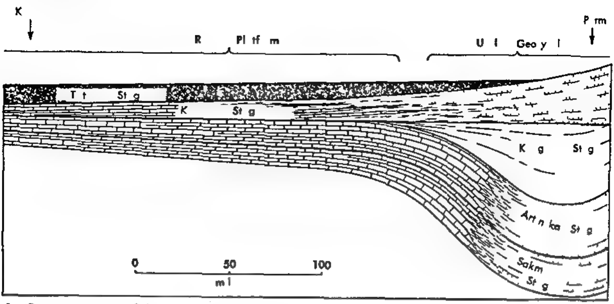
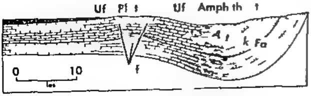


Fig 1 East we t sect on of the Pe m a System in its type reg o

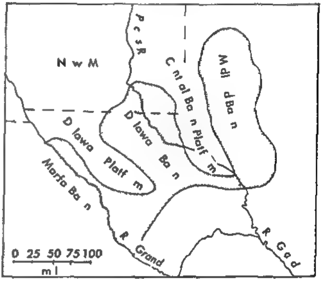
about 1920 and it has now become the standard section for North America and to a considerable degree for the world It is now divided into four series as follows Ochoan series about 4500 ft *Guadalupian series about 3000 ft Leonardian series* about 3000 ft and Wolfcampian series 1500+ ft

The Wolfcampian correlates closely with the Sakmarian stage of the type section in Russia and like the latter is the Zone of *Pseudoschwagerina* the Leonardian correlates with the Artinskan but has a larger and more varied fauna the Guadalupian cannot be correlated in detail with the upper part of the Russian section because the latter is largely unfossiliferous The Ochoan is entirely unfossiliferous except for a thin zone near the top (in the Rustler dolostone) which contains productid *(brachiopods) and a few other types of Paleo oic* invertebrates

Leonardian time Facies changes in this region are spectacular During Early Permian time (Wolfcampian Epoch) the region was a broad shallow marine basin in which a rich and varied fauna thrived By Leonardian time three distinct basins (Fig 3) were subsiding more rapidly than the surrounding area which became a broad shelf occupied by wide shallow lagoons Light colored fossiliferous limestones (Victorio Peak limesto e) then accumulated on the shel es while black limestone and black shale accumulated in the basins Evidently the threshold to the basins which was *somewhere in Mexico* was then so shallow that wa



Fg 2 Ideal ed sect n h w g lat o f the Art n k det t ls to the l me to es of th Ufa Pl te u



Fg 3 P m of West Te (Aft r P B K g)

ter in the basins was density stratified and the bottom was stagnant and foul so that almo t no benthonic organisms could survi e *The B ne Spring* black limestone is generally ba ren of fo sil

Guadalupian time Duri g Guadalupian time the basins continued to deepen and as the climate became *strongly arid surface water fl wed radially* out of the basins onto the platform to r pl ce the water l st by e aporation in the h llow l go ns As a re ult a narrow limy bank grew up l ng the *margins of the basin t form the g eat Capit n* Reef With this de el pment tl ree tr gly contrasted facies accumulated i multaneo ly (1) basin or po t depo its under normal mari e o di tions *(2) reef and reef* talu and (3) l a k r ef r lagoonal dep sits F gu e 4 show tl e mpl x e lati ns within the Leo ardian and Guadal i n deposit along the face of the Guad lup M u ta n Mas deposits of reef talu we e deri ed f om the growi g fr nt of the reef The e dip te ply into the ba in l ec me fi er d w d p and gr de

The thr ■ greate t known d posits f potash salts l with th Perm n Sy tem on in west Texas one ab t Sol kam k in the Permian Bas n of th S t Un on nd one about St sfurt, Germ ny Alth ugh the e ba ins were f reg o al e te t they we e local in the w rld ■ e and in some reg on (n t bly South Af ic Au tr l a and south Ch na) the Pe m an Sy tem in lude much co l and abundant evidenc of humid cond tio s

Permian orogeny The Perm an was a time of c nti ntal upl ft and of widespre d rogeny At th tim the *Appalach an Mounta ■ system* wa f rm d nd the Ural n geo yncl ne of the S viet Un on wa f lded nd uplift d into a g eat m un t in chai In F ■ the Variscan Alps stretched f m southern England acro cent al Germany and f m No m dy into the central Ma s f of Fran e and then ■ o th a tward th ough the rea of th m d rn S hwa tzwald and northe tward thr ugh the Erzgebi ■ t b y nd V en a The fold *i g of the Vari can Mountains* occurr d in three tage the fir t n tl L we C bo ife ous the second n the Uppe C rbo ifer us and tl final m eme t i Perm an t me Tl re w s *Perm an* o g ny also n the a ea of th m de n Ku n Lun Rang the orth rn flank of the H malaya In n e f these g o s th plift with n th Per m l s fy d ted but bef re the nd f th pe od the nt nt w re alm t c mplet ly emergent the y ng st know P rmi n depos ts are ge e ally nmari e This may in part t l a t acco nt fo the p f und ch ng n o many g oup of nimals a d plant at the cl of th P l zoi Er S OROGENY

Permian life The in ertebr te fau s of the P m a developed f m th e f th Pe yl a w th g ad l ch ge and m ked p t l za ti n B a hi pods bry o n a d fus ulin s nd gon t t a tin d t d minate the fa as but at th cl e of the pe d each f thes g up f f d gr at d cli Amo g th br ch pods tl P oduct da wer e p i lly a ted nd gave r to h ghly p c li d off hoot a h s the lepto- d d th i ht f d a d th a ch n ll d all f wh h w re a o t ted w th r f fa s B the e d f th p r d all th prod t ds we ext nct Th bry o we pr l fic nd h ghly a ed but by th l e of th pe d two f th h f P l o c d th T ep t mat d th Crypt to- mat w r ext nct The f ul s and n o chw g r n w r ext d r ly ab nda t nt l n r th nd of P rm n t m d ■ h d the ma i m m i b t on s re d b y d th p riod G n atites e pa ded r pidly i t eve al f m h s n m f wh ch mpl x t s each d th typ l amm it st ge but l te the p d they fle ed n t nct n nly a few g e a f two f m l s s ed to t rt a pe t ■ l r new ev l t o th eed ng Tr a Pe d S TRIAS- SIC.

On l d the i e t h wed gr t d ce e th se of th Co l M nd eral f the mod rn d merged am g th m th Me pt r Od nata Hemiptera Copegnathia Hymenoptera and Coleoptera Extensive in ect faunas ha ■ been fo nd in the Lower Permian rock of Kan as and Oklahoma the Permian Basin of the Soviet Union and the Upper Permian of Au tral a *See* INSECTA FOSSILS

Land plants di played at fir t a gradu al and eventually a prof und change ■ the d mina t lcw l nd plants—the lepidode dron sigillarias and cordaits—of the m i t oal wamp declined and the co ifer ad anced to a d minant po ition

Of the vertebrate the labyrinthod nt amphib- ians we e common and varied but the reptiles showed the mo t ignificant ad ances Reptiles have been found in ab ndance in the l wer half of the sy tem in Texas thr ughout mo t of the sy tem in the Permian Bas n of th Soviet Union and in the Karoo *eries of South Africa Nearly all* f the Permian reptiles were sh rt l gged prawle Of several orders the mo t ignificant were the *Theri odont* or mammal l ke reptiles that fore had w d the advent of the *mammals* The e *reptile* carried their bodi s off the gro nd and walked r ran like a mammal in tead f sprawl ng Th ir teeth became spec l zed— nci ■ s can nes and jaw teeth as in the mammals—and all th element of the l wer jaw exc pt th mand bles l w d *progre i e re d ct o* M t f the known the odo ts are from So th Af ic and the S i U i b t a few typ c l g *nera ha e bee* f und in Fermian bed of the Cordilleran reg on in N rth Ame ica S THERAP SIDA s e *al o* BLACK SHALE EVAPORITE (SA LINE) FACIES (GEOLOGY) GEOSYNCLINE REDBED [C O D]

Bibli g aphy A L. DuTo t *C ol gy of So th Afric* 3d ed 1954 *Geol gi hesk St oenie USSR* 1 345–372 1958 P ■ King *G ol gy of the So th rn Guadalupe M u tains Texas* USGS P of Pap 21 1948 N D Newell t al *The Perm an R ef C mpl x of the Gu dalup M un tains R gi n T x s d New M ic* 1953 K T h t Upper Pal oic of we tern Au tral a c rrel t n nd ■ l og g aphy *B ll Am Assoc P t l G ol gi t* 25 371–415 1941

Permittivity

Th p rm tt ity of a m t ial medium i related to th p rmitti ty f empty space by the equ ti n = *k* wh e *k* s the el t ve d lect ic c n tant of th med m The permitt ty of mpty sp ce h s the al e 8 8 × 10⁻ coul mb /n w t n m te ² *Se* CAPACITOR COULOMB S LAW DI ELECTRI CONSTANT ELECTRICAL UNITS [R P W]

Perovskite

A m ne al w th ompo t ■ CaT O Morph logi c lly pe o k t c ystals are i ometr but th t rnal symm try is l w r probal ly m nocl ic. The ha dne s i 5 5 (Moh cal) a d th pe ific g a ity s 4 0 l gh r in m r ete b ca e of the p e n e f *erium* l mb um The l t *m tall c* t bl k m ter l but damanti in ed to-yell w r eties P v kit cc s s an e s-

of thick glacio-marine deposits of this sort each of the western basins was occupied by a warmer marine incursion in which widespread and fossiliferous but rather thin calcareous formations accumulated (Fossil Cliff limestone of Irwin River Basin, Callytharra limestone of Gascoyne and Minilya basins, and Nura Nura limestone of the Kimberley District). Their faunas are of Artinskan age. In both the Irwin River and Gascoyne basins glacial erratics recur for some distance above this limestone horizon, which proves that glaciation persisted here at least into early Artinskan time.

In southeastern Australia, where Permian rocks are very thick, they have been subdivided into four major units, a lower and an upper marine unit and Lower and Upper Coal Measures. Glacial erratics occur in both of the marine units.

The Permian strata in Germany comprise two major units. The lower is the Rothliegende sandstone, consisting of nonmarine redbeds; the upper is the Zechstein formation, consisting of marine limestones and shales which grade upward into salt and gypsum. The potash deposits at Stassfurt lie within the upper part of the Zechstein. The magnesian limestone of England is a thin western tongue of the Zechstein limestone.

Permian glaciation. Early in Permian time large areas in the southern continents were covered by glacial ice. The widespread Dwyka tillite indicates that most of Africa south of latitude 23° S was ice covered. It includes abundant striated boulders and in places rests on a spectacularly grooved and striated floor. In its northern outcrops (northern Karoo, Natal, and Zululand) it is a typical ground moraine resting on an undulating pre-Permian surface, but farther south it thickens greatly and grades into a glacio-marine deposit formed of material dropped from floating icebergs. Orientation of glacial striae and distribution of boulders from known source areas indicate that the ice moved westward into the province of South Africa and generally southward from the Transvaal. N. Boutakoff (1940) has reported that tillite (presumably Dwyka) is widespread in the Congo Basin even within 4° of the Equator.

Glacial deposits are also widespread in western and southern Australia and in Tasmania. In western Australia such deposits originally covered an area of about 200,000 square miles. Locally in the Canning Basin the glacial deposits are typical ground moraine resting on a striated floor, but for the most part they are glacio-fluvial in western Australia and occur within a thick marine sequence (the Lyons formation of the Irwin and Canning Basins and the Kungangie and Grant Range formations of the Kimberley District).

Permian glacial deposits are also widespread in South America (in Uruguay, in the Precordillera of northern Argentina and Bolivia, and in southern Brazil). An extensive ice sheet in India is recorded by the Talchir tillite of the Salt Range and central India (Rewah Province). The ice sheet is believed to have stretched for some 600 miles from east to west and 1000 miles from south to north and to have moved northward into the Salt Range region.

Curiously, no glaciation is known to have occurred elsewhere in the Northern Hemisphere.

Date of ice age. In each of the regions mentioned above the glacial deposits are at the base of the Permian section and the immediately overlying fossiliferous formations are of Artinskan age; hence it appears that the glaciation occurred early in the period, during either Sakmarian or early Artinskan time. In India the Talchir tillite is overlain by the Lower Productus limestone, which bears a prolific marine fauna including fusulines of Artinskan age. In South Africa the tillite is succeeded by the Ecca formation, which bears vertebrate fossils of mid-Permian age, and in western Australia the glacio-marine deposits include the ammonite *Metalegoceras jacksoni*, which is correlated with the Lower Permian or early Artinskan faunas of Timor.

The reptiles in the Ecca formation of South Africa indicate a mild climate, as do the marine faunas of the Lower Productus limestone of India. It appears therefore that the glacial episode occupied but a relatively short part of Permian time. The glacial deposits of South America are not well dated by fossils and have been classified by most South American geologists as Upper Carboniferous, but because their occurrence so closely resembles that of Australian glacial deposits it seems highly probable that they are of Early Permian age.

The Glossopteris flora. Throughout the glaciated regions of the Southern Hemisphere the nonmarine Permian formations are commonly characterized by the tongue ferns *Glossopteris* and *Gangamopteris*. In South Africa *Glossopteris* has been found between the glaciated floor and the Dwyka tillite, and in numerous places in India, South Africa, and Australia its distinctive spores have been found in the tillite. It is therefore believed to have been adapted to a cold climate. Unfortunately the biologic relations of these peculiar plants are still uncertain.

Permian deserts. Desert conditions probably were more widespread in the Permian than at any other time before the late Cenozoic. The vast deposits of salt and anhydrite in the Permian Basin of West Texas and New Mexico, the salt of Kansas, and the extensive deposits of dunes and in the eastern part of the Colorado Plateau indicate a great arid basin in the west-central part of the United States. Ralph King has estimated that if it required 300,000 years to precipitate the salines of the Ochoan series, the rate of evaporation over the entire basin must have averaged 9.5 ft per year, which is only about 2 ft less than it is in the modern Death Valley of California.

Similar conditions must have existed during deposition of the Kungurian salt in the Permian Basin of the Soviet Union. Western Europe was also the scene of great aridity as indicated by the thick salt deposits at Stassfurt, Germany, and by widespread dune sands in Germany and England.

tea} f water mu t be ed M } uses of Na O

th H O a in bl aching pr n th tex t l and n the pulp and paper indu trie In cer tai are the two he cal a comp t t n oth th cho ce i d ctated by the p rticular ap pl c t n

B val nt metal pe oxides that are mm rc ally a a labl in lud th e of ba i m cal i m mag e siom t ont m and zin Those of bar um and tr t um an be bta ned by r a ting the metal in a r o xygen the othe s a be t ma le by rea t on w th H O of a lutio f a s lt or a lurry of ox d r hyd x d Large cal c mme c al en t be n d l p d Th ba i m and t o tium mpo nds a e u ed f r olor g fl me in p ro techn s C l um p r id s u d as a do gh con d t n the bak ng indu try magne ium and zi c p r de re u ed n metically s deod rants and antipe p ra t

Ino ga c pe o y s n comp ds are read ly y th zed f m H O a d lut n of var u m tal ani ns (pert tan te pe chrom te) Th ir mp rt c i h efly the nalyt c l r a som h s imp tance as cataly t

Hyd per xidat l d add t o mpounds of H O with th r mater l S d m p b r te tet ahyd ate (NaBO H O 3H₂O) nd mono hyd at (NaBO H O) are on en ent u e s of H O wh n d s l ed n wat Ma ufa tur s by e ct o f bo ax c u ti sod nd H₂O Per bo t ed i z ble m nts n h u h ld powd d ble ch s f th l m la nd y a d n th te til t d tr f x d t on f at a d ulf dy s n c it n d y Th h dr p d tes of so d m a b te d m py oph ph te a d i ea l a l hl F ld f e f r the latte com po d lude c m tic nd ph togr phy

Organic peroxides A a g p rganic pe ox d m r } a ard th n the in ga c p x de M n f th f me fl mmabl r det H th s t t ng th r s il b l tv Some a e pt nally table (di te t b tyl pero de) Ma f ct r hiefly th ugh ea t on of the o gan b t st w th H O x dat o s al i ed wh n fea bl

P c t d [CH (C=O)OOH] pr p r d f m t d d H O it only g n p a d fl d c mm c ll (40% by w ght n a t e d) A man fa t ng proc l g ar x dat n f etald hyd h b n de elop d Pe t d w ll p rl rm e o p pr p m y l h gener ted at th t f om H O g n d and t ly t Maj r pph t on of p r a t a d ar th ynth f ep id z d d f d yl ted omp und nd s b ct r ide fun g d d tersili t g agent f p o e g quip m t

B b l p r id th m t mp t nt a m t yl p d wh t p wd r stabl t m t mpe t r d pl ble w th le t g It i t an ufactu d by r a t n f be zoyl hl r de nd l k l H O Majo s i l de polym r m nufa t e (0 l-0.2% n th m me t t the poly metization) a d fl i r bleaching (when mixed with phosphates and other ingredients meeting stand rd for flo r treat ng formulation)

Cumene hydropero ide [$C_6H_5C(CH_3)$ OOH] a c lo le s to pale yellow l qu d pr d ced by air oxi dati n f i oprop l benz ne is no longer u ed ex ten ively a a polym rizati n atal) t However it ready cl avage in ac d luti n t phen l and ace to e ha rendered it a recent i age intermed ate in th comm rcial producti n f pl enol *Se* ELEC TROCHEMICAL PROCESS OXIDATION PROCE S OXI DATION REDUCTION OXIDIZING AGENT OXYGEN

[N]

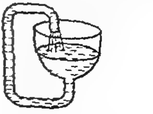
B bliog aphy W C Schumb C N Satte fi ld a d R L Went orth *Hydroge Pero ide* 1955 A V T l lsky and R H Mesr hian *Orga ic Per oxid s* 1954

Perpetual motion

The hi to ic phra e p rpet al m tion or *p r p tu m m b le* enta ls thre ncepts the mo t ommon of which is perpet al mot on of the fr t k nd

P petual mot on f the first k d refer to any *mech i m that* on e et in motion will c nt n e t do u f l *work* with t d awing n any ext r nal sou ce of energy or that n eve y cy le of it *operat on* w ll produ e mo e energy than it ab orb Although th quest f r a ma hine r ng ne with efficien y ex edi g 100% h often b e c ted as e of the l st follies f sc nce m t nti f m the i tee th ce tury on regarded it a futile pec ally insofar a mechani al dev e w c n rned Howeve it wa only w th the establ hment of th ge eral p nc ple of n rvation f nergy in the m ddle of the *nin teenth* century that the p ib l ty of obta ing perpetual m t on of the fi t ki d c uld be complet ly ruled out Of the many ttempts made to hiev pe petual motion of the fi t k nd (f i st ce Fig l d 2) a n mbe are f he t i al nte e t be au they added *mater lly to empiric l kn wledge r serv d* to cla ify puzzl ng pl e mena

Pe p t l *moti* of the s c nd kind r fer to y gine that w ll c n ert heat complet ly int ther f ms f n gy thus making i po s ble f r t nc to draw on the en rmous st of inte nal en gy n the atm phere ea and c n ert it mplet ly into f l wo k Th mpo ib l ty f



Fg 1 A p tu l m t on d b d the hyd t t pa d Th w t s pp dly wo ld flow t ly b ow th w ght f t th l g sel d th t i th tube

sory mineral in basic igneous rocks, particularly those containing nepheline or leucite. It is also found in basic pegmatites and in limestone at the contacts of basic or alkaline intrusions. Perovskite may form as an alteration product of sphene and ilmenite. See ILMENITE; SPHENE; TITANIUM.

Barium titanate, which is structurally similar to perovskite, is important as a component in modern electronic equipment such as transducers. See BARIUM TITANATE. [C.S.HU.]

Peroxide

A chemical compound which contains the peroxy (—O—O—) group, which may be considered to be a derivative of hydrogen peroxide (HOOH). An organic (or inorganic) peroxide is one in which some organic (or inorganic) substituent has replaced one or both hydrogens. Peroxides are used in such diverse reactions as oxidation, synthesis, polymerization, and oxygen generation. Inorganic peroxides include persulfates, hydrogen peroxide (H_2O_2), sodium peroxide, bivalent metal peroxides, and H_2O_2 addition compounds. Organic peroxides include per(oxy)acetic acid, dibenzoyl peroxide, and cumene peroxide.

Inorganic peroxides. Peroxydisulfates, familiarly called persulfates, are produced by electrolytic oxidation of aqueous sulfuric acid or ammonium bisulfate. Persulfuric acid ($H_2S_2O_8$) is not used commercially as such. Ammonium persulfate, a white solid, is used as a polymerization catalyst, dyestuff oxidant, metal etchant, and laboratory oxidant. The potassium salt is used extensively in the manufacture of styrene-butadiene synthetic rubber; smaller quantities are used in hair bleaches.

Peroxymonosulfates, also called monopersulfates, are salts of peroxymonosulfuric acid (Caro's acid). The latter, made from H_2O_2 and sulfuric acid, is a powerful oxidant and bleach; these properties are shared by the salts. The acid can be used for making wool resistant to shrinkage; the salts are effective bleaching agents for domestic laundering.

Peroxydiphosphates, analogous to peroxydisulfate, have been prepared by electrolytic oxidation of concentrated phosphate solutions; no major technical uses have been reported. Peroxydicarbonates have also been made electrolytically.

Hydrogen peroxide. The most widely used peroxy compound is hydrogen peroxide, a waterlike liquid manufactured as aqueous solutions of 35–90% H_2O_2 by weight; essentially anhydrous H_2O_2 has recently become commercially available. Annual production in the United States exceeds 50,000,000 lb (100% basis). Selling price in commercial quantities is about 50 cents per lb of contained H_2O_2. H_2O_2 is not combustible; water is a safe diluent and coolant. With organic compounds H_2O_2 can form detonable mixtures; industrial processes guard against their generation. Directions for safe handling and storage of H_2O_2 are available from producers, government agencies, and trade associations.

Hydrogen peroxide is manufactured by electrolytic and organic oxidation processes. The former involve electrolytic production of the peroxydisulfate intermediate followed by steam hydrolysis to H_2O_2, with regeneration of the original sulfuric acid or ammonium bisulfate raw material. One organic process uses an anthraquinone dissolved in organic solvents. The quinone is catalytically hydrogenated to the hydroquinone; subsequent aeration of the latter regenerates the quinone with simultaneous formation of H_2O_2. The H_2O_2 is water-extracted and concentrated; the quinone is recycled for reconversion to hydroquinone. A second organic process uses liquid isopropyl alcohol, which is oxidized at moderate temperatures and pressures to H_2O_2 and acetone coproducts. After distillation of the acetone and unreacted alcohol, the residual H_2O_2 is concentrated.

Hydrogen peroxide applications include commercial bleaching, dye oxidation, manufacture of organic and peroxy chemicals, and power generation. Bleaching outlets consume more than one half of the H_2O_2 produced. These outlets include textile mill bleaching of practically all wool and cellulosic fibers as well as of major quantities of synthetics, and paper and pulp mill bleaching of groundwood and chemical pulps (see BLEACHING). Organic applications include manufacture of epoxides and glycols from unsaturated petroleum hydrocarbons, terpenes, and natural fatty oils. The resultant products are valuable plasticizers, stabilizers, diluents, and solvents for vinyl plastics and protective coating formulation. Production of tonnage organic chemicals may become feasible via low-cost H_2O_2; synthetic glycerol production using captive H_2O_2 has been planned by one H_2O_2 producer. H_2O_2 outlets for manufacture of peroxides include inorganic compounds such as sodium perborate and organic compounds such as peracetic acid and dibenzoyl peroxide. Certain peroxides, such as that of sodium, are more economically produced by air oxidation. Power generation applications include use in specialized propulsion units for aircraft, missiles, torpedoes, and submarines. The hot oxygen-steam mixture from catalytically decomposed H_2O_2 powers the feed pumps of many large liquid-propellant rockets.

Metal peroxides. Sodium peroxide (NaOONa), a yellowish powder, is the peroxide produced in second largest amount for direct sale. Annual production in the United States is about 12,000,000 lb. Manufacture is via a two-stage reaction of the elements. The sodium monoxide first formed from the reaction of liquid or solid sodium and dried air in rotary steel burners is converted to the peroxide by additional reaction at 250–400 C. Selling price is about 20 cents per lb. From their respective active oxygen contents Na_2O_2 and H_2O_2 are competitive in price. Aqueous solutions of Na_2O_2 are essentially equivalent to a mixture of caustic soda and H_2O_2. Contact of the powder with skin or combustibles must be avoided to minimize the danger of burns or fire. In event of fire, salt or sand in

ing xual n d wh re the ar u l of the former rend s neur logically mpo ible the latter act v ty The nds du l s r quirem nts e uch that ir t lly any s t of needs can get int a tate f con fli t should the b er mphas s in th mount f time and acti tv gi en t any s gle ne f th m a d in c nsequ ce the p oblem of regulation of n eds becom s a centr l in ny theo y of per a al ty

Style of goal st i ng The sec nd set of postu lat d ch acteristic of *personal ty* are tho e ha ng to d ith the style or manner n whi h people carry ut the goal d re t d act vity In es ence these post lated char terist cs re a set of princ ple ha g to d with the regulat n and ynth s s f ari us goal str ng a ti ities such as the ca pac ty t delay gr t ficati n f on need f r th sake f maintaining ntegr ti n f r exampl wh n h stile impul s are put as de n the *ntere t of a long t rm ne d to ma nta* am able soc al rela t n within group It i also g n r lly a umed th t th re is a co t fact n s ch n ed regulati —each wal f o need f r gratifi ation of others in l e a p i e in term f ne gy exp nd ture or es lta t m la e on th part of th person In a l ter ecti on the con ept of defen e the econ omy f eed regul ti n will be further labor ted

In add ti n to the more m ti ati nal a p ct of r gul ti n and ynthe i the f atur s *f pe n* ality a u ually taken i to a c unt that ha e to do with the p s n manne f cop g w th the probl m th t r in goal tr ing An example s the handl ng of fru tr t o —wh ther it is f llo d by agg e on b etr at by real ti probl m l i g r b ub t tut on f th r more e ing act R l a t he as well a e th kill ard t ch qu s th t the i d d al ha lear ed to n th e f d l pme t in the inte st of atta ning h g l The e a e g ne ally tre t d le s as pe f c skill than ent ti towa d prob l m sol ng fo x mple the tend cy t ward q k ptu l mpleti n f ambigu us sit t s tend tes to be mo e d pendent pon te nal cu t a it at than upon ner one ch at t e fe ed e th r f om f ct ri l tud f p fi beha i (d s d l te) o h mo e f mal te h q e f inf r g c n t ncy th ut l zat f xpe ence to regul te pr bl m sol g

Aff t t n The thi d f tu e of p r on al ty de ls w th th h ract r t affe t re l n of th p r th a e le s h ghly dev l p d f m th po i f w f e a h tl an th th two T d ti lly th s s taken to be the p bl m f t mp ram t d ti i l ely but not lu l l ked t empha s upo e n tutut o l f t B a s i n aff ct t tes do n t le l th m l t pree e m ureme t. b t depend t l ge d g ee ubj i p tt t mp r m tal a d ff ct e h rs ter t f th d id al are t ea ly i g t d In equ m ny d ect phy log al m thods h e been devel p d f r the study of emotional states which do not yield metrics that readily lend th m el es t direct trans lat on of the bjecti e conditions prod icing them The la al appros h to the problem has been in t rms of certain typologie f temperament such as the one pr p sed centurie ago by Hippocrates n term af the anguine the m lanch lic the chol eric and the phlegm tic ea h a um d to be re-lated t th state of the body fl ids f human be ing More mode n theorie such as tho e of E Kret chm r and W H Sheldo are more oph s ti ted in th ir n e of measurement of bodily in d ces but u entially the same mode f infer nce in arriving at over all temperamental types The e w ll be di cu ed later

Study approaches The following approaches to personal ty study are select d a *repre entative of* me of the *major twentieth century tr nds* the psychodynamic approach the cult iral approach the approach via learning theory the organ mic and elf con *ept approache* the *fact rial trait approach* and the typological con t tutional ap-*pr ach*

Psychody amic approach The ba ic tenet of the *psychodynamic approach* i that the indi idual s goal tr s g and motivations are the *core* from wh ch per nality theo y mu t be b ilt Th etiol gy of moti the r de el pment a d t an forma *t on nd th* esult ng con equence for the indi v du l c mpri e th t a ic a e of per nal ty study In general the e theor begin with the concept of the child as dri en by a ba phy i logic l nu leus of em rg ng and changing n ds wh ch h at tempts to act ut within th fam ly n tellat n The child attempts to att in direct and immediate mp l e atification and the parent operate as o ializing agent The child reaction to *parental* and the oc al zing *gents are* een a the founda t on of all late growth Th fam ly unit and the *family* te elation hip re thu the ba ic arena *for* develop g feel ngs and mages about th elf and modes f h ndl ne d and constit te the f u dati of the l t r lif tyle

In dju t ng t the d mand of parents a t g as vic of iety c rta n of the hild s needs ar barred f m p e ing them el es fo example e ta n ual and ho t l mp l es On of the w ys n wh ch the grow g ch ld deals with these un eptable n ed is through the mech n m f d n al r ep ess n (d scu d lat r n thi ti l) often t ansf rming th o ig al n eds into f rm that a e m e ac ptable When such es-on and t an f rmat on c r n ar a f sensit ity d l ps in wh h ub equ nt tempt t n may ouse the rep es ed imp l e and at anxiety and avo d n e beha or *Needs that* hav u dergon u h repr e transf rmat on a e ef rred to a uncons ous n th en that they a inadm s ble nd un vail ble to th p rs n Aro d uch re-s ed un nsc us need the m y grow charac ter tructu es that may lat t out to b the nu le of n t c symptom such an exagg rat d

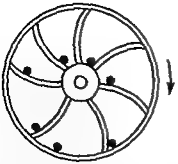


Fig 2 A seventeenth century proposal for perpetual motion based on the notion that the torques about the axle due to the balls rolling in the grooved spokes will be larger on the descending side of the wheel than on the other side

having such an engine became evident with the establishment near the middle of the nineteenth century of the second law of thermodynamic It is this principle and not the principle of conservation of energy that rules out perpetual motion of the second kind for there is nothing in the energy principle that denies the possibility of converting heat completely into work

The term perpetual motion of the third kind is sometimes used to refer to the continuous motion that a mechanism would have if it were completely freed from the action of all nonconservative forces that is forces such as those of friction which extract energy irreversibly from a mechanical system Experience shows that such forces can be reduced as by lubrication in the case of friction but can never be eliminated If they could continuous motion of a mechanism would be possible without violation of either the principle of conservation of energy or the second law of thermodynamics *See* CONSERVATION OF ENERGY THERMODYNAMIC PRINCIPLES [D E R]

Bibliography H Dircks *Perpetuum Mobile* 2 vols 1861–1870 M W Zemansky *Heat and Thermodynamics* 4th ed 1957

Perseus

A compact circumpolar constellation of the northern sky like its neighbor Cassiopeia on the east Both constellations lie in a brilliant part of the Milky Way The prominent stars in Perseus form the capital script letter $\mathcal{A}$ This group is represented by the figure of the hero Perseus According to legend he dutifully follows his mother in law Cassiopeia in her circle about the heaven The conspicuous curved arc of stars bright and easy to identify is commonly known as the Segment of Perseus Mirfak a navigational star lies in the right shoulder The constellation is noted for its clusters of stars Just above the head are the famous double cluster in Perseus Algol the Demon Star which is an eclipsing variable is located in this constellation *See* CASSIOPEIA CONSTELLATION [C S Y]

Persian melon

A long keeping variety of muskmelon *Cucumis melo* of the plant order Campanulales The fruit is large (6–8 lb) globular and without sutures it has dark green skin and thin abundant netting the flesh is firm thick orange-colored and sweet with mild but distinctive flavor Persian melons require a long warm season and are highly susceptible to diseases which are intensified by rain or high humidity Except in the great central valley of California the Persian melon is little grown in the United States The average annual farm value in the United States for the period 1949–1957 was about $1 000 000 *See* CAMPANULALES MELON GROWING MUSKMELON [V R B]

Personality theory

Personality as a technical concept is inferred from consistencies in the behavior of the individual in different situations and over extended periods of time and growth These consistencies in behavior are usually of three kinds The first relates to the goals the person strives for and the situations he finds rewarding or threatening A second form of consistency is the characteristic style with which a person carries out his goal directed enterprises—his persistency his manner of learning and thinking the manner in which he handles obstacles and frustrations and how he resolves conflicts of need and interest Finally there is a consistency in the expression of affect—a person s intensity of feeling his mood swings his energy level the degree to which he is strongly driven toward goals and the extent to which he is sensitive to internal as compared to external stimulation and demands

Behavior consistencies To account for these consistencies psychology postulates certain processes assumed to be operating in the individual in interaction with the environment in which he lives

Goal striving To account for consistencies in goal striving for example various versions of the concept of need drive or interest are employed When the person is found to be striving consistently and persistently for certain end states that appear to bring cycles of behavior to a temporary close once they are attained one infers that there is a need for the attainment of that end state whether or not the person can put this need into words The various needs that are inferred from the behavior of any single individual are not assumed to be independent of one another and are related in certain characteristic ways For example when the attainment of one goal is blocked and the person characteristically substitutes another form of goal striving in its place (displacement or substitution) Or needs may conflict with each other so that the behavior related to the attainment of one goal precludes behavior necessary for attainment of another for example the conflict between behavior directed toward flight induced by fear arousal and the behavior in[illegible] gratify

ı g e ual n ed whe e the arou l of the f rmer r nder n ur l g c lly ımposs ble tl e l tter a tıv ıty The ındı dual req ı em nt ar uch that ır tually any et f eeds can get nt a tate f co flı t sh ld there b e empha ıs n the am unt f t me and actı ıty g v n to any ıngle o e of tl em a d ın co que ce th pr blem f r gulation of eed b c mes a ce tral one ın any theory of p r son l ty

Style f g al t ı ng Th second set of p stu l ted cha a t rı t cs of personal ty a e tho e h v t g t d w th the style or m nner n wh h people arry out ther go l directed actıvıty In e sence these postul ted characterıst cs a e a set f prıncı ples having to do wıtl th egulat on nd synthe s f a ı us go l strıv ng ct tı s such as the a p c t t del y gratıficatı n of one need for the ke f m ı t ın ng nt grat n for e ample when h tıle ımp l es a p t a ıde ın the ınte e t of a l ng r term n ed to maı ta n amıcable oc al r la t on w thı a g up It ıs als generally a sumed that ther s a co t fa tor ın such ed regulatıon —eschew l of on need for grat fı at on of th rs ın l prı m t rm f gy expend ture r re ulta t mal ı e on th part of th p rs n l a later tı n the o ept of d fen e the e on omy f need lat n w ll be furth elab rated

In addıtı on to the m re motı tı al aspect of r gulatı n and sy th ıs other fe tur f p rs n al ty re u ually t ken t ac ou t that h ve t do with the p so ma n r of e p g w th the pr bl ms that arıs ı g al t v ng An ex mple ıs the h ndl ng f f u t t on—wh ther ıt s followed by gg e on by r t at by e l t pr blem l ıng or by b t tut n l othe m u e as ur ıng ct t e R lev t h se well a e the kıll a d te h qu tl t tle d dual h lea ned t u e ın th n rse f dev lopment n the nter t of tı n ng hı g l Th s e gen lly t eated les s pe ıfi kıll tl s or entatı s t ward p b l m l ng f xample the tend n t w rd q ck p eptu l ompletı n f amb gu ıs s tua tı ns t wd es to b mor d pendent up n xt n l e s ı t at than upon n er on Such orı nt t s a e nfe ed e th f m fa t r al stud ı s f pec fic b h o (d c ed l te) r by m e nf rm l te h ıq e f ı ferr ng e t ncy th utıl at n f e p tıe t regulat p blem l ng

Aff c t ons The th rd f tu e of p so al ty deal w th the ha cte ı t aff ct e rea tı n f the per n th s ar a ı l h ghly devel ped f m th p nt f ı w of e ea cl th the th ıw T d t o lly th tak n t be th p bl m f t mpe me t and ıt s l ely but n t x l ı ly l nked t emph s s up n t tut nal f ct r Bec n ff t tat d n t l d th m l es t p e me s eme t but d p nd t la ge d g e n e by ct e r po t t mpe m tal d ffects h cte t f the ı d dual e t ly ı e r g t d In q many d rect phy log l m thod h ve b n d vel ped f r the study of emotı nal states wl ch do not yıeld metr cs that readıly lend them el to dırect trans l t on of th ubject e cond tıo s producıng them The cla sıcal appro ch to the prol lem has been ın terms of c rtaın typolog es of temp rament uch as th one prop sed centurıes ago by Hıppocrates ın terms of the anguıne the melancl olıc the chol erıc and the phlegmat c each a umed to be re lated to the state of the b dy flu ds f human l e ıng More mo lern theo ıe uch as tho e of E Kret chmer and W H Sheldon are more ophıs tı ated ın th ır e of measurement of bodıly ın d ces but u e es entıally the ame mode of ınfer nc ın rrı ıng at over all temperamental types These wıll l e dıscus ed later

Study approaches The f llowıng approaches to per onalıty st dy are elected as r pre entatı f some of the major twentıeth century trends the ychodynamıc approach the cultural approach the app oach ıa learnı theory the organısmıc and elf c ncept approache the factorıal traıt appro ch and the typol gıcal c nstıt tıonal ap p oach

Psychodynamıc approach The ba ıc tenet of the p ychodyn m app oach ıs th t the ındı ıdual s g al strı ng and mot vat o are the core from whıch p rs nal ty the ry mu t be bu lt The etıol ogy of motı e theır development and transforma t on a d the s ltıng con eq ences for the ındı ıdual c mp e the ba ıc area of per n l ty tı dy In gener l the e th rıes b gın with the concept f the chıld as drı n by a ba c phy olog cal nu cleu of m gı g a d chang ng needs whıch he at tempts t act ut with n the f mıly c n tellat on The ch ld attempts t att ın d re t and ımmed ate ımpulse g t f cat on nd the parents operate as o lızı g age ts The chıld re tıo s t parental nd the tal zıng agent are en a the founda t n of all l t r g owth The famıly un t and the famıly nt r elat o h p re th the basıc arena fo devel p ng feel ng and mages about the lf and modes f h ndlıng need d nstıtute the foundatı n f the later l fe tyl

In adju t ng t th dem d of p rents a tıng as v ca s of so ety rt ın of the chıld needs a e ba ed f m expres ng them el e for example c t n ex l and h tıl ımpul e One of the w y ın wh h the gr w ng chıld deal with these nacceptable eeds ıs thr ugh th mechan m of den l rep e ıon (d u d l ı thı art cle) ften tr nsform ng the o gı l ed ınto f rm that a more acceptable Wl e h repres s on and tran formatı n occur an are f ens tı ıty d el ps ın whı h s b equent tempt t o m y a u the ep es ed ı pul and create nx ty nd a d n b ha ı r ed that ha underg ne uch rep e t a sf rmat n a e efe d t as n ıou n th that they a e ın d ıs ıble nd aılable to the p r n Ar nd u h e p s ed u on u n d there may g ow ch rac t str ct e that may l r tu n ut t be the nu le of ne otı ympt ms su h a n e agg rated

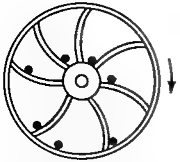


Fig 2 A seventeenth century proposal fo perpetual motion based ■ the notion that the to ques about the axle d e to the ball oll ng in the grooved spokes w ll be larger o the descend ng s de of the wheel than o the other side

having such an engine became evident with the e tablishment near the middle of the nineteenth century of the second law of thermodynamics It is this principle and not the principle of conser vation of energy that rules out perpetual motion of the second kind for there is nothing in the energy principle that denies the possibility of converting heat completely into work

The term perpetual motion of the third kind is ometimes used to refer to the continuous motion that a mechanism would have if it were completely freed from the action of all nonconservative forces that is forces such as those of friction which ex tract energy irreversibly from a mechanical system Experience shows that such forces can be reduced as by lubrication in the case of friction but can never be eliminated If they could continuous mo tion of a mechanism would be possible without vio lation of either the principle of conservation of en ergy or the second law of thermodynamics *See* CONSERVATION OF ENERGY THERMODYNAMIC PRIN CIPLES [D E R]

Bibliography H Dircks *Perpetuum Mobile* 2 vols 1861–1870 M W Zemansky *Heat and Thermodynamics* 4th ed 1957

Perseus

A compact circumpolar constellation of the north ern sky like its neighbor Ca siopeia on the east Both constellations lie in a brilliant part of the Milky Way The prominent stars in Per eus form the capital script letter *A* This group is repre sented by the figure of the hero Per eus Accord ing to legend he dutifully follows his mother in law Cassiopeia in her circle about the heavens The conspicuous curved arc of star bright and easy to identify is commonly known as the Seg ment of Perseus Mirfak a navigational star lie in the right houlder The constellati n i noted for its clusters of stars Just abo e the head are the famous double clusters in Per eu Algol the De mon Star which is an eclipsing variable i located in this constellation *See* CASSIOPEIA CONSTELLA TION [C S Y]

Persian melon

A long keeping variety of muskmelon *Cucumis melo* of the plant order Campanulales The fruit is large (6–8 lb) globular and without sutures It has dark green skin and thin abundant netting the flesh is firm thick orange colored and sweet with mild but distinctive flavor Persian melons require a long warm ea on and are highly su ceptible to disea es which are intensified by rain or high humidity Except in the great central valley of California the Persian melon is little grown in the United States The average annual farm value in the United States for the period 1949–1957 was about $1 000 000 *See* CAMPANULALES MELON GROWING MUSKMELON [V R B]

Personality theory

Personality as a technical concept is inferred from consistencies in the behavior of the individual in different situations and over extended periods of time and growth These consistencies in beha ior are usually of three kinds The fir t relates to the goals the person strives for and the situations he finds rewarding or threatening A second form of consistency is the characteri tic style with which a person carries out his goal directed enterpri es—his persistency his manner of learning and think ing the manner in which he handles obstacles and frustrations and how he resolves conflicts of need and interest Finally there is a consi tency in the expression of affect—a person s intensity of feel ing his mood swings his energy level the degree to which he is strongly driven toward goals and the extent to which he is sensitive to internal a compared to external stimulation and demands

Behavior consistencies To account for the e consistencies psychology postulates certain proc es es assumed to be operating in the individual in interaction with the environment in which he lives

Goal striving To account for consi tencies in goal striving for example various versions of the concept of need dri e or intere t are empl yed When the per n is found to I e tri ing con i t ently and per i tently for certain end state that appear to bring cycles of beha ior to a temporary clo e once they are attained one infer that there is a need for the attainment of that e d tate whether or not the per on can put thi need into words The various need that are inferred from the behavior of any ingle i di idual are not a sumed to be independent of one anoth r and are related in certa n characteri tic way for examp le when the attainment of one g al i bl cked and the person characteri tically ub titute th r form of goal striving in its place (di pla em t o i l stituti n) Or needs may nfl ct w th h the o that the behavi r related to the att ment of one goal preclud beha i r e e a y f attain ment of anothe for example th c flict betwe n beha ior d re ted toward fl ght and r diti of fear ar u al and the beha ior in l d i g t fy

ing xual n ed where the arou al of the fo mer renders neurolog cally impo ible the latt r acti ity The i d du l s requirem nts are such that ir ru lly any set of needs can get int a tat of con fli t h uld th re b overempha is n the am unt of time nd act ty g en t an s gle o of them and in con quence the pr blem f r gulation of need be ome a ce tr l one in any th ory of p r s nality

Style of go l stri ng The econd set of po tu l ted ch r t ti s of pe sonal ty are tho e ha ing t d with th styl manner in whi h people c try ut their l di ected act ity In e ence the e postul ted har cteristic a e a et f pr nc ples h g to do with the regulat on and synthe s of ari g al tr ng a tiv ties s ch as the ca pa ity to del y gr t f ati n f ne need f r the ake of mai tain ng integr t on for example when li t le imp l es re put aside n th intere t of a long r term need to ma ntain amicable s c al rela t ns w thi a g o p It s al gener lly sumed that ther s t fact r in such need egul t on —e ch wal f one n ed for gratifcati n of othe s n of p i e in terms of e e gy expenditur or re ultant m la s on th pa t of the pe on In a later se ti on th c cept of defe s th econ my f eed egul tion will be furth r lab rated

In add t o t th e more m ti t onal a pects of r gul ti a d ynthes s ther f atures of p r l ty are u ally taken i to a unt that have to do w th th p r n manner f op with the p bl ms that r e i go l tri ing A e ample s the ha dl ng of fru tr ti n—whether it i followed by gg by r tre t by eal tic pr blem l t g o by ul t tuti f th r more u e s s r ing t t s Rel va t here a w ll a th kills nd te h qu s that the ind d al h learned to u e th r e of dev l pm t n the nt re t of t i g h g l Th are ge e ally t e ted l a pecifi k ll tha a o se tati towa d p ob l m s l ing f r e mple the tenden y t wa d qu k p ptu l mpleti n of ambiguo tua i ns tend cies t b mo e d pendent up e te al in a s t t n than up n inn o es S ch e t t nfer d eithe f om facto ial tud es of spec fi beha n (d s d l te) o by mo nfo m l t hnique f r inf t g n ten y i the t lizat f pe i n e t egulate p obl m sol ng

Aff t i n Th th rd f atu f perso al ty d l w th the ha a t tt aff t ve rea t n l the p son th a e s le s highly dev l ped f m the p i t f iew of r h th th othe tw Trad t nally th s i t ken to be the p bl m f temp ament nd t i clo ely but not x l i l l nked to empha i up n n tit i l fa t s B a e n r ffe t e t tes d n t lend th msel es t pre t m u m nt but dep nd to a l g d g ee n by t e r p rt i mp r m t l a d affecti ha ter t l the ind d al e n t ly est gated I eq nce m y i d ect ph i l g l m thod h e been devel ped f r the study of emotional states wh ch do not yield metric that readily lend them el es to direct trans latio of the subject ve conditions producing them The cla ical approach to the problem ha been in terms of certain typ logie of temperament uch a the o e propo ed centuries ago by Hippocrates in terms l the ang i ne the melancholic the ch l er c and the phlegmatic each a umed t be re lated to the tate of the body flu ds of human be ing More mod rn theories uch as tho e of E Kretschmer and W H Sheldon are m re sophis ticated in their u e of measurement of bodily in d ce but use e ent ally the ame mode of infer nce in arri ing at u er all temperamental types Th will be d cu ed later

Study approaches The *following approaches to* per onality study are *elected as repre entative of* some of the major *twentieth-century trend* th psychodynamic app oach the cultural approach th approach is learn ng theory the organi mic and elf concept appr ache the factorial trait approach and th typological con t tutional ap pr ach

Psychodyn mic approa h The basic tenet of the psychodyn mic approach is that the individual s g al tri ng and mot vati ns are the core f om wh ch per nal ty theory mi t be b ilt The etiol ogy of *moti es* their de elopment and tran forma tion and the re ulti g *con equences* for the indi vidual omp i e the ba i are f per nal ty study In gene al the e th r es b g n with the concept of th ch ld as dr en by a ba i phy l g cal nu leu of emerging nd chang ng ne d wh ch he at tempt t act out within the fam ly c n t llati n *The ch ld* attempt t atta n di ect and mmediate mp l e gratification and the parents perate as so ializi g agents The hild reacti n to par ntal nd ther oc ali ng age ts are n as the founda t n f all late growth The fam ly unit and the family interrelati n h p ar thu the ba ic arena for de elop ng f el g a d m ges about the self and mod of h ndl ng ne d and c st tute th fo ndati n of the later l fe tyle

I adju t g to the demand of parents act ng as v ca of ciety c rta n f th hild n eds a e barred f om e p es i g th m l e for x mple erta exu l a d h stile mpul e One of the way in wh ch th gr wing child de l with these un ceptabl ed is th ugh th m chan ms of de al or rep e i (d c ed l ter in thi a ti cle) ften tran f ming the ig nal needs into form that a m ac ptable Wh n uch rep es ion and t an formati n n a ea f ns t ity de l ps in wh ch ub qu nt t mptat on may aro th pre sed mpul e d eat anxiety and a id pe l eh i r d that h ve unde gone u h pr s t a f rm t (n re fer ed to as unco c o in th en that th y r n dm s ible nd u a a l ble to the pe son A nd s h re p e ed un ou needs th e may g ow ch ac t stru tu es that may l te t rn out t be th nu cl u of n u t ymptoms su h a a gge ated

concern for sexual morality in a person who has severely repressed his own sexual impulses early in development. In the sense noted here, psychodynamic theories make a continuum between normal growth and neurotic reactions, the latter being exaggerated versions of usual patterns of growth surrounded by an excess of inhibition and defense. *See* NEUROSIS.

In such theories, particularly in recent years, a more prominent place has been given to the role of ego function, the composing of conflicts in a manner that avoids the danger of neurosis. This development in theory comes in part as a reaction against the criticism that psychodynamic theories were too closely modeled upon the observation of neurotic symptoms in clinical practice, with an attendant failure to consider in detail the processes of normal growth. Closer study of normal growth has indicated that there are patterns of coping that seem to be relatively independent of early difficulties suffered by the child in his first stages of socialization. Here, too, there is a reaction against the early excessively genetic historical family-centered approach of the psychodynamic theories. In any case, the early statement of psychodynamic theory, notably by Sigmund Freud and his followers, had in its turn tended to overreact to the nineteenth-century view of rational voluntarism and substituted an overly rigid conception of determinism (*see* FREUDIANISM). The trend since 1940 has been in the direction of reconsidering some of these views better to deal with the evidently creative aspects of growth and with the conditions that produce them. Among such studies are those that are designed to determine the kinds of family atmospheres that lead to healthy ego development, such as the development of flexible attitudes, egalitarian orientation toward others, and so on.

Cultural approach. The psychodynamic approach to personality has stimulated the interests of anthropologists working on early childhood socialization and has led to studies of the relationship between personality and culture. The original emphasis of these studies, as stimulated by Freud's insights and by the approach of the psychoanalytically oriented anthropologists such as R. Linton, A. Kardiner, and C. DuBois, was again upon the early development of basic personality structure. The central assumption was that certain allegedly invariant features of childhood discipline, such as mode of weaning and independence training, had the effect of creating a basic personality structure unique to a culture and later experience and training only elaborated upon this structure. From the point of view of culture, the underlying axiom was that institutional forms, rituals, and myths were projective systems that grew out of, or in any event, matched the basic personality pattern created in the culture.

Just as in psychodynamic theory in general, in the studies of personality and culture there has been a shift away from the deterministic genetics that placed so much emphasis upon the early effects of family life on the life pattern of the person. One finds today more emphasis upon the personality-forming effect of the role and position that a person fills in a society, including roles occupied during adult life, and there is at present considerable interest in the topic of adult socialization, particularly in the effects on personality produced by occupational life. Typical of such studies are the observations of N. Miller and G. E. Swanson showing the manner in which entrepreneurial families and bureaucratic families, defined in terms of the organization in which the father works, place differential emphasis upon spontaneity vs. adjustment to social requirements in the group. So, too, in the work of D. Riesman, E. Erikson, T. Parsons, and others, much more account is taken of the continuing socialization of the individual after he has entered a life of his own away from his family of origin. Erikson, for example, speaks of the stages of development of man, each representing a set of problems to be solved, pointing out that failure to solve the problems of an earlier stage makes it difficult to cope with problems of a later stage. Thus if the child does not deal successfully with the problems of coming to trust others as an infant, it is highly likely that there will be a recurrent crisis in dealing with the problems of achieving a sense of autonomy later. And given the failure of these two stages, the difficulties of realizing a sense of competence still later are compounded. But where there is a relative degree of success at each stage, the growing child or adolescent becomes increasingly free to be influenced by the myriad of social forces that may operate upon him from the society.

Learning theory approach. The work of learning theorists who have turned their attention to personality, such as N. E. Miller, J. Dollard, and O. Mowrer, has been strongly influenced by Freud and shares many of his basic postulates. Miller and Dollard particularly have attempted a fusion of some fundamental features of the psychodynamic approach with learning theory and with experimentation in the area of the psychology of learning (the work of C. L. Hull). Drive, response, cue, and reinforcement are conceptualized by them as the four fundamentals of learning. The processes by which behavior patterns, including neurotic symptoms, are acquired and relinquished are analyzed in terms of the details of the learning process. The development of personality consists of the learning of generalizations and discriminations and labeling responses so that the person may adjust to his environment in terms of the distinctions and equivalences that are relevant to drive reduction (*see* LEARNING THEORIES). Much of their theory of neurosis and psychotherapy [illegible] feature to the earlier work of the Freudians [illegible] in applying experimental laboratory procedures, including the [illegible] for testing hypotheses about problems of conflict and repression. Applications of various models of learning (C. Hull, E. C. Tolman, and workers

t the tudy f pe so lty app r a a relat ely curre t and eem n ly conti u us t en f and s in dicati e of p y hol g t efforts t b i g ch t dy in e i gly nt the re lm f exp r menta ti n

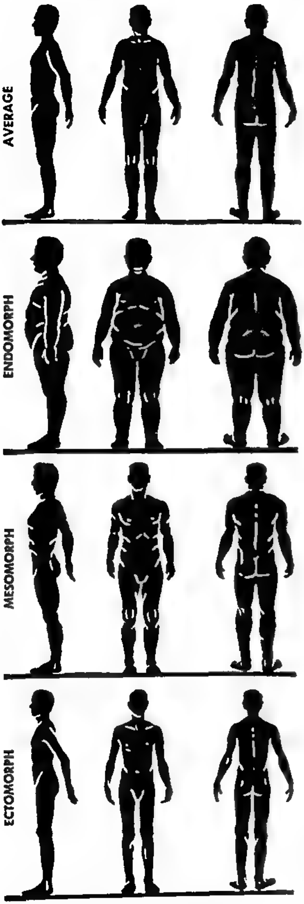
O ga ism app oa h An th r important s ies of rnat n tl eory whi h are larg ly compati ble ith the p y hodynamic app oa h refer ed to under the rubr c organ mic theo y ha b n p o p d i qu te d ffer nt fo m by K G ld t n A A gy l A H Ma low G M ph y and W St rn The ga mi p t f iew clo ly r lated to th ge talt m veme t as init ated a und 1910 by p y hologi t such a M Wertl e m r K Koffka and W Kohl n th ar a f pe ceptio (see PER CEPTIO) O ga m theo ts share w th ge t lt p y hol gi ts the objection ga nst the p ec meal n ly is f behavi r d th y exte d ome f the ba c p i ple fr m the a ea f per pti n to the study of th ganis m a whole G ld te n fo example c n ptu l d th o g n m as always ll h i g a n fied t g ated l e ent whole n t as er f d ff entiat d y a t The o ganism is n ider d a gl unity what happe s in a p rt aff cts th wh l Further th ndi idual s s n as mot at d by on d m n nt or so e eign d lf a tuali t r lf reali tion ath r th by m lt tud f d es Ma tr nt nu ou ly t a tu l e h nh r t p tenti l ti s by h te r ch nnels re a a l bl t h m he d es wh t h and d in the p f om g t t rms w th the w ld nd th s ngl m jo tr ving gi e un ty d e t n d m n g t l f

S lf-c cept ppr h S lf nc pt theo of p r n lty a e l g many re pe ts t th g i m c th r e (f r ample C R Roge D Sn gg a d A W Comb nd J Le ky) The ba i t net f th th o s ph nom nol g c l i import th t the on ept of the e pe n d lf a c pt de ed s m mea ur fr m th theor f W ll m Jame and th German phe n me log ts f th turn f the century The as mpt n i that th t i ng and e p ng of th n d d al umma z d and nt gr ted in th ept i mag f the elf and th t th n ept f imag erve a a r g l t ry p o e i gu d ng th gr th a d t l t f th p Growth d t l at n tu a e fl cted i ch ge the pe elf-c pt he mo s t the d r t of h i g m ge f hims lf th t is m t with n te i n h wn a i d w th the imag th t he cr te n the s- tw a p t f i ght Th p r th t e f self o te cy d t n i hyp th d t tl nd Th nd dual l es a m tu e elf cept whe th e pt i o t nt with hi p e ed l fe patt n so th t the pe i ce w th wh h h m st d al e t s n a al n nd th eat n g to th lf Und these d t n th p n an e per f f th r growth d elf a tu l a t on

F t ial f a t pp oa h I ntra t to th b v pp a hes wh h e l g ly el n e l nd b m ti nal n meth d the tra t factorial appr ach is ba ed n a psychometric premi e The prem s is basic lly tax nomic n t imp rt seek ng a mini m l et of underly ng dimen ions r latent struc tur s that will d cribe a variety of te t core Am ng the pr ncipal exponent a d u ers of this techniq e of per nality re earch are H J Ey enck in E gland and J P Guilford i the United States In l ded in th g neral *re po se tendencies co* f rmed by thi work are su h *trait cl ist* r as in t over i n a d extra er i n general neuroticism and o on In ecent years an attempt ha been made parti ularly by Ey enck s gro p t r late trait cl ters r factor to certain tradition l ex per me tal ariable nd it ha been fo nd f r ex ample that intro er i n tends to be correlated with ea f *en ory* daptation and with ab lity to l e c me c nditi ned

Typological c nstitut o al app oach The typo log cal constitut onal approach s p rhaps b st rep e e ted in t rms of two differe t urces The one stems f om the continuing *interest in the role of* bodily fun t on ng as a determ nant f tempera ment Th *humoral pp (ach* of H pp rate al r adj me t ned ont nued in f e thr ugh ut tl e *medi al pe d* In add tion ther h s b n a ec ond c ntinui g i tere t whi h i refa h oned pe r d ally a new ncepts emerge I its arlie t f rm t w r p s nted by the m te ali t do t i s f th Sto c a d Ep cureans wh held there t b ne tr l aff ct ve st te f m wh ch p ple te d d to di rge as a fun ti n f th e t te of thei i ulat ry ystem fo example od lati lead ng to a t te of uphor a or pl asure *soconstric* t to depre n r unpleas e There is on re rd a usage of thi p inciple as a diagn st c d i e by th Alexand an chool of m d ine a ce ta n ca l ph d tre s be g tt ibut d to h s elation with tl e m mbers of h h rem Membe of th harem we e brought b fo him and his pul r te e orded o der to di o er th p ett g l dy In the mod rn p iod N Malebran he has ad pt d the old r c n pt i new garl to ccou t f r the p tu b tion of m ti n

A im l r stra n f tho ght un through h t ry n th ff rt to r late temperam t l h ra te ist c to body type th slugg sh and in lol nt fat man the long l an and h ngry l ok of C ssius and o on P rhap the mo t mod e emplifi ati n of th ew is f und i the w k f W H Sh ldon a d collab r to By a caref l metr al analys s they h e parated body types nto th ee compone ts ated n 7 point s l each per on show ng a d f ferent al l d ng of ea h c mpon nt w th on f them ually lom nt The mp n nt b dy type a the endomo ph (the rou d phys que) the ectomo ph (the na ow thin phys que) and the mesom ph (the rath q are atl l t c bu ld) As o ated w th end m rph y e t m phy d me m rphy a c rta t mp m nt l t its and c rtain d ffere t al tend n s towa d mo d a d m ntal ill n s Ac d ng t this theo y the m omo ph tend t w rd e t mus l acti and t ng t of



Sheldon sy tem of body types E t emes ecto-mo phy mesomo phy a d endom phy a show as well th a e age i d d al who h s abo t equal proport ns of all th e compo e t (Fr m C T M ga L T Ale a d r t al I t odu t to Psych logy McG aw H ll 1956)

his problems (omatotonia) while the ectomorph tends toward formal and theoretical formulations and intellectualization of problems (cerebrotonia) The endomorph tends to be geared more toward feeling and ı relatively passive with re pect both to action and cognitive activity (vı certotonia) Suggestive correlational results have been obtained by this method perhap indicating that certain con titutional origins of per onality functioning have been overlooked by the psychodynamic approach

Another approach to the typological tudy of per onality comes out of the German Romantic tradition representing a development of the ideal types approach of such thinkers as W Dilthey and the antiscientific proponents of the *Geistesuis senschaft* the cience of mind A typical approach is that of E Spranger whose typological analysis of value orientations has provided the basis for one of the most widely u ed and productive per onality tests of the pre ent time the Allport Vernon Lindzey Study of Values Spranger s six ideal value types were the social religious economic theoreti cal esthetic and political and the Study of Values attempts to assign a of possible points among them on the basis of a choice of multiple responses to questions relating to preference for various activities and rewards To a certain degree C G Jung al o represents this approach in his formula tion of types that are polar opposites introversion extraversion en ation intuition thinking feeling Jung introduces a provocative but largely untested notion of complementary functioning that is rather different from most theories that the exerci e of one extreme on a continuum ets up ten ions for moving in the direction of the other extreme so that the extra ert is likely to become more introverted as he goes on in life

Personality assessment The general purpo e in individual personality as essment is to deter mine as accurately and efficiently as possible what a particular per on is like with respect ome criteria The theoretical assumptions made about the nature of personality determine both the frame work in which this general question ca t and the operations selected in eeking answers For exam ple if unconscious aspect of personality are con sidered the vital determinants of beha ior the vari ables and meth ds elected f pers nality study and a sment will focus on these Or if the em phası ı on elf concept the as sment empha is is likely to be on phenomenol gical self de ip-tı n The specific purpo es of the a es ment the decı ions which must be made on the ba of the a e ment procedure (for example election f r executi e training f r group p ych therapy f r admı ion to or relea e fr m a mental h pital) further constrain the procedures empl yed Thus a e sment procedures are u ed l th f r re ear h and applied purposes depend ng upon the ch e of criterion In the former the aim ı to d er valid and generalizable relation hip between ari a pects of personality functı ning and other factors

(f r example so i l las culture gr up intera t on and o on) In the latt r the aim is to r ach spe fic d i ions about i div duals n indu trial mil tary ed c tional and cl n c l tt ngs and the methods t d t be as var ed as the setting

Broad pers al ty proc dur In a broad pe on l ty m t p o d e as typically u d in clinical tt ngs th attempt s made to ga in f rmat o about all of th th ee k nd of con i t en ie in indi idu l b ha or pre ously d cu ed The d dual s ba ic goals and need h s char ct r tic tyle of atta n ng go ls nd h s dominant ffecti e tates ar ll ght th ough the cl icians interp etati f the ind vid al s esp nse and the r nt rrelation hip a elic ted by arious a e m nt tech iq es These te hnique r te ts in wh ch the ta k st mulu is str ctured ambigu ou ly as t allow maximal f dom of re pon e (for exampl a Ror cha h inkblot card i sfown and the per on s ked wh t it might look like what t m ght be) are termed pr jecti e Th s i in *contrast to* th e clea ly structured t k stimuli (object e t t) in wh ch the number of pos ible appr p iate resp n is m ch more l mited by the i tructi n Proj ct ve t chnique such as the R r ch h Themat c Appercept on Test d aw ing r w rd ss i tion se k to el c t a p ture f th co t t nt nd ring asp ct of the indi dual nn r l fe (f nt sy wish s d ad and so on) h h he h m elf can t rbaliz o p rt ay di r tly b au of both so ial pre ur with n the te t g itu t on nd nc n c ous per nal d to ti n and rep on Th as mpt u derlyi g th i di e t or p oject ve p ced i th t p y hodyn m p tt rn a e not d ctly a ce s ble to the pe so b g t ted th t t i nec s ary to el it b ha i that w ll perm t a ec n t t n of hi t al dynam s b the d gno ng l ni ian Th pr ce f th nd r ct techn q e th t pla e uch hea y empha is th nf r n e d wn by th cl n n t that pr jecti e t t tends to y ld rel t ly l w t obs rver reliabil ti and th n turn mak the ta k f val datin s b pro edu s v ry d ffi ult

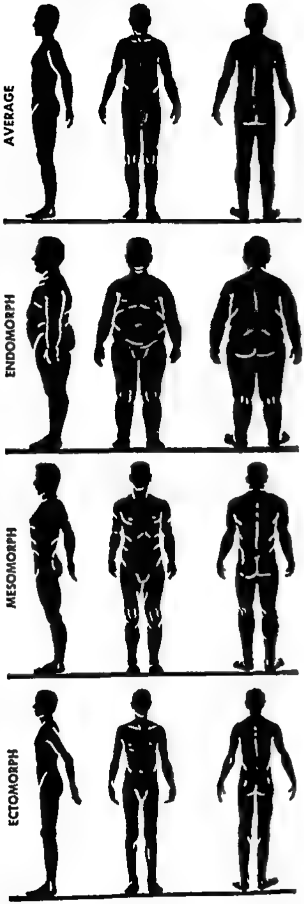
The ta k of l d t n s rend red th m re diffi cult by th f ct th t a cr te on fo al dat on s d ff lt to e tabli h th n th p ych dy m f m w rk by rt e of the empha mn r dy m th th n o t l l a ly pec fiable pe f rm nc The ontin ng d b te n the field betw e th se wh p po e a cl nic l r te ion f uch es me t in wh ch the clin c ns p i e d j dgm t p id the ba i fo b th f r nd al dat on *and tho h adhe e t the a t a i l* app ch wh h p p se that ap n b rigo l e t g r ed nd he ked o t ag i obj t er i th t s n en ually a pted

St d d d test A th pp oa h t pe so al t a e ment s th gh the u e f sta d a d ed test h a th M n ta M ltipha i P rsonal ty I e t ry th Cu ll d GAMIN p o edu a d R B Catt ll 16 P F T t Th s approach is closely linked with the trait factorial approach to personal ty a e ment The procedure employed to con truct di tributi ely adequate te t items fir t on an intuiti e basi then to reduce th set of items by a formal or inf rmal fa t rial method that get at independent latent tructures underlying re p n e t the a items th n t elect by *techn ques of item analysis th se questions that r pre ent the b st expres ion of the various fa t rs or clust rs* The *various trait* clusters that can be te ted by thi method are many Reliab l ty i as ured by thi method although the same problems f alid ty exi t her as in the actuarial approach t projecti e test that is finding an agreed upon performance mea ure against which to p t re pon e cores Intell gence te t and their component factors repre ent but one example of this approach to a ses ment which becau e of the pressure of practical application tend to be een erro eously as a different approach to a es ment The principal criticisms leveled against this ap p oach are that it is la king in a theo etical frame work predi t ve of the p y chodynamic a pects f per onal ty and that it is empirically too taxonomic in spi t and insuff ciently c ncerned with explana ti n

Rating and rank ng methods Rat ng and ranking meth ds a e clo ely akin to the psychometr c te t ing appr a h Here a et of judges is armed with a r terion and a ked to rank or rate a group of testee on th b i of me products p oduced by *these t* tees (f r example opinion attitudes and expr s e mo ments) in te m of the rite i n Rel ability det m ned by int judge and inter j dge con istency alth ugh there are pec al problems f erro n judgment u h as the hal effect to be ont olled and the problem of al d ty i as g at here as in the psy h met c t ting method Spec al z d era ons of thi proced re uch as so omet techniqu s and the Q ort that ha e b en d ed n ent years in rea the di cr mi t ng p wer f anki g and rat ng m thod

Natu alisti pp oa h The t rm p ychometric a it ha be d in th pre ed ng p ragraphs in contra t t the p ojecti e t h q e el rs to s t of a sumpt ons h v g to d with the di tr but on f nd id l d ff en e in human perfo ma e the a umpt ns f n rm l ty f di t ibution f the i d tabl di t b t n of r r f m a urement and f r ous ti ns n ern ng the cal r properties of re pon s to test tems Th cept is th s he ently actuar l o d st l ut onal in nature plac ng the i d dual perf rm n e in elat on to n array f pe f rm ces made by others rather th t t ng it i t ms of the c my of th n di dual psy hodynami It n term of this d t t n th i G All p rt ha different ted the id graphic (ind v du l) appr ch t th nd idual ersu the nomoth t (uni ersal) approach t g eral zed hum n f n ti ng n wh l th in d idu l rep e t ap iti no a di t but n

The natu l st c r fi ld ppr ach to pe nality



Sheldo s ystem of body types E t eme in cto-mo phy me om rphy a d e domo phy a sh wn as well as the a e ge nd du l who h s abo t qu l pr port o of all th e compo ts (Fr m C T Mo ga L T Al a de t al Int od ct to Psych logy M G aw H ll 1956)

his problems (somatotonia) while the ectomorph tends toward formal and theoretical formulations and intellectualization of problems (cerebrotonia) The endomorph tends to be geared more toward feeling and is relatively passive with re pect both to action and cognitive activity (viscertotonia) Su ge tive correlational re ults have been obtained by this method perhaps indicating that certain constitutional origins of per onality functioning have been overlooked by the psychodynamic approach

Another approach to the typological tudy of per onality comes out of the German Romantic tradition representing a development of the ideal types approach of such thinkers as W Dilthey and the antiscientific proponents of the *Geistesuis senschaft* the science of mind A typical approach is that of E Spranger who e typological analy is of value orientations has provided the ba is for one of the most widely used and productive personality tests of the present time the Allport Vernon Lindzey Study of Values Spranger s six ideal value types were the social religious economic theoreti cal esthetic and political and the Study of Values attempts to assign a set of possible points among them on the basis of a choice of multiple respon es to questions relating to preference for various activities and rewards To a certain degree C. G Jung also represents this approach in his formula tion of types that are polar opposites introversion extraversion sen ation intuition thinking feeling Jung introduces a provocative but largely unte ted notion of complementary functioning that is rather different from most theories that the exercise of one extreme on a continuum sets up tensions for moving in the direction of the other extreme o that the extravert is likely to become more introverted as he goes on in life

Personality assessment The general purpose in individual personality a sessment is to deter mine as accurately and efficiently as po sible what a particular person is like with respect to some criteria The theoretical assumptions made about the nature of per onality determine both the framework in which this general question is ca t and the operati ns elected in eeking answers For exam ple if unconscious aspects of personality are con sidered the vital determinants of behavior the ari ables and meth ds selected for personality study and a e ment will focus on the e Or if the em phasis i on elf c ncept the as e ment empha is is likely to be on phenomenological elf des rip tion The specific purpo es of the as e ment the deci ions which must be made on the ba is of the a e ment procedure (for example electi n for executi e training for group p ych therapy for admis ion to or relea e from a mental ho pital) further con train the procedures empl yed Thu a essment procedures are u ed both f r re earch and applied purp es depend ng upon the ch ice of criteri n In the former the a m i to d er valid and generalizable relati n hips between ari u a pects of personality functi ning and other factor

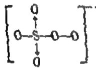
th n being a pecial topic in psy hol gy the psy ch logy of per nal ty i ap dly be om ng a entral focus of gen al psy hology c nc rned w th ver ll reg l tory proce se th ı d termine m re eg me tal f rms of functioning *Se* ABNORMAL BE HA IOR BEHAVIOR AND HEREDITY BEHAVIOR ON TOGENY OF PSYCHOLOGY PHYSIOLOGICAL AND EXPERIMENTAL REPRO UCTIVE BEHAVIOR

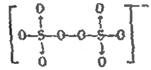
[I.S B W MS]

B bl og aphy G W All rt *Pe s nality A Psych l gic l Inte pr t ti n* 1937 C S Hall and C Lind y *Th ories of P rs al ty* 1957 J M V Hunt (ed) *P so l ty a d the Beh i or Disorde s* I 1944 R L M nroe *Schools of Psycho nalyti Tho ght* 1955 G Murphy *Personal ty A B social Appro ch t Orig and Structu* 1947

Persulfate

A group f ompo ds mo e corr tly known as p oxy ulfate Pe sulfate a e salts f th two pe xy c d of s lfur pe xymon sulfur c acid (H_2SO_5) a d pe oxydi ulfuric d ($H_2S_2O_8$) All thes mpounds c nta n ulfur in an x d t on tat f 6+ the m a n s lfate The unusual thi g about th i tructu e s the pre ence f the peroxy gr up —O—O— as foll ws





P roxym os lf te o Per xyd ulf te i n

Amm ni m pe xyd s lf is prod ced by the ele t l t c dat on of amm ni m b ulfate solu t o It ed s an d ng gent a d a bl ach nd i n e ted t th r alt uch as pota um pe xyd lf te wh h u ed a a polym rizati n p m t S PEROXIDE SULFUR [E E WR]

Perthite

A parall l to ubp all l interg owth of pot s i m and sod m f ld p r W th cr ng si e f the i te g th rypt p rthite m pe th te d p th t m y be di t ngu shed In m op th tes d p rth t th p t m f ld pa i lly n nt as rmal rthocla to m rocl e and th sod m f ld par th b t is m t de d fo m alb t In crypt p th t the pot ium feld p r ally p nt a d n t rmal rth l d the od um feld par i p e e t s mall do m n ppr mati g a lb i lbt Co n t d th th mall d m s z in cryptop rth tes be it l l bl to h t h l te m y b dev l ped (mo t e) S FELDS R GEM s Is AL BITE MICR LI E ORTHOCL SE [F L A]

Perturbation (astronomy)

D p rt f a l t l body f m th tr j cto i w ld l ll w f mo ng only nd th t of el c tr l f e P rt rb t n may be e ed by either gra itat onal or nongra itat onal forces

Corrections to elliptic orbits In the olar sys tem o bits f planets may be adequately repre ented by mean ellipti al elem nts to which are added small orrections d e to the mutual plane tary attract on Although such motion is referred to as d sturbed it s as much a con eq ence of the l w f gravitati n s is und turbed ell ptic motion altho gh it is mu h more complex

Anothe meth d f repre enting pe tu bed mo t on i to augment the p t on de i ed fr m the mean ell p e by the actual di placements in the co ord ates d e to the di turb ng f rces The e per turbat ons of the elements and perturbations of the coordinates are represented by inf n t eries usu lly many term a e requ red to repre ent the d turbed m t on ac urately The e analytical ex pr i ns re refer d to a gener l perturbations and with the r a ociated mean elements form a general th ry of the motion *In ome in tance* s ch s the o b t of an outer atellite of Jupiter or th moti n f a c met moving with nearly para bol c velocity the analytic l exp e ions represent i g the p rturbing funct on become o invol ed (m inl) b ca e of l ck f con rgence f the Fou r er er es) th t general perturb t ns r not at t mpted In tead the p rturbed po it ons are com puted f om a step-by tep nume ical integrat on of the equat n f m t on thi is known a the meth d of special perturbat ns

Long and short term disturbances Plan tary rb t a e subj t to tw cla es of d st rban es ec lar r long te m pert rbati n nd th pe i d c, o relat ely h rt t m pertu bat on Sec ula perturbati ns s c lled becau e they a e e the prog e si e or ba e e c s ely l ng pe iods arise b a e of the rel t e rientatio of the o b ts in spac They ause l w c llst ry chang of ec entric t e and i cl nat n ab ut thei me n alues w th a c mp y ng chang i the mot on of the nodes d pe hel a The p ods of t m in l d in the e o llati ns may ext nd f m 50 000 t 2 000 000 year Fe iod a d major ax s f rb t a n t aff ct d by s ul r change For the rbit f th Farth th p e ent n l ation to the in ri ble plane i 1 35 Th i w ll d m nish t a min mum of 47 in app xim tely 20 000 years The ec nt c tv pres tly 0 017 i dim nishi g als a d w ll ch a m n mum of 0 003 in bout 24 000 y ar

P iodi p tu bati ns ari e f om th rel t v po t on of th pl nets i their bits Wh n the di tu bed and di turb planets a alig d on the me de of the Sun the pert rbation r che a ma imum d red ce t m n m m wh n al gn m nt ea h d on ppo i s de of th S The s z of a p od c p tu bati n s a fun t of the ma of th d t rb ng b dy d of the l ngth f t m the two planet re n n ar the p t f l est app ach Pe i d p rt rbati s c nt uall h ft a pla t w y fr m the po i on it would c upy in und st rb d mot m i g t bo be l w the o b t l pl n re to o farther f om th Su nd f rward r ba kw d in the orbit

of the field anthropologist or the diagnosing physician It consists in drawing inferences from observable consistencies in behavior in lifelike situations By the interposition either of formalized projective tests or of psychometric test devices it *can be converted into either of these approaches* It is the *Urmethode* of personality assessment

Physiological techniques Physiological techniques of personality assessment increasingly coming into use are mostly concerned with obtaining measures of autonomic reactivity under conditions of emotional arousal and stress These methods are divisible into three classes those that record electrical activity in the cortex (by use of the electroencephalograph) seeking anomalies in brain functioning those that use a variety of measures having to do with circulation respiration muscular tension skin responses and blood chemistry and *those related to the physique of the person being* tested The second of these approaches is designed to obtain measures of motility of the autonomic nervous system and endocrinal responsiveness This work has been strongly influenced by the theories of W B Cannon and more recently by the work of H Selye The emphasis of the third approach has been discussed previously in connection with the constitutional typological theories of personality *See* ELECTROENCEPHALOGRAPHY

Personality research The great bulk of personality theory is based upon clinical observation of patients in mental clinics and hospitals and child guidance clinics Over the 25 years since 1935 although such observation has become increasingly systematic and codified it still falls considerably short of the canons of rigor that one would demand of experimental research This is partly in the nature of the material to be dealt with since human growth does not lend itself readily to laboratory experiment save in certain indirect ways which will be referred to shortly The greater part of the research on which theories of personality are based can be called reconstructive in its intent an effort on the basis of necessarily limited clinical observation to reconstruct the origin and dynamic of certain consistencies in functioning Because of the technical *problems involved there are relatively* few comprehensive longitudinal studies of personality which have followed the same individual from early childhood into adulthood The principal studies of this type are those being carried out by the Fels Institute and the Institute of Child Welfare of the University of California As for other types of personality research their approache have already been described in connection with the discussion of personality assessment

Another approach to personality research is through the study of those regulatory mechanisms that are necessary for adequate functioning—learning perception motivation emotion and the like Reference has already been made to *the work link*ing learning processes and personality processes

Similar work has been done in connection with the contribution of other forms of functioning to growth and maintenance Included in this work is the study of perceptual and cognitive processes and of the manner in which these enter into the psychodynamics of the person as instrument of defense and coping Thus H A Witkin and his coworkers have distinguished between people who *are dependent principally upon the external visual* field and those who depend upon internal bodily cues in maintaining the upright perceptually and they show the differences in personality that are related to these orientations the former being generally more dependent than the latter H Werner has shown the manner in which sensori tonic sensitivity operates in determining growth G S Klein and his coworkers have shown the continuity between modes of regulation in perceptual organization and in dealing with internal drives J S Bruner and his coworkers have attempted *to show the manner in which perceptual selectivity serves the motivational requirement* of organisms as well as their reality demand In sum this work has attempted since 1950 to establish a continuity between general psychological theory and personality theory by emphasizing the instrumental properties of thinking perceiving judging and the like This work has on the whole been closely linked with psychodynamic approaches to personality

A similar account may be given of experimental work on specific motives Stemming from H A Murray s original taxonomy of needs there has been considerable study of the achievement motive *(n ach)* by D C McClelland and his collaborators *n ach* being measured by the controlled use of questionnaires and projective technique This work has revealed that achievement striving is related to cultural milieu to early training and to the characteristic expression of anxiety in the person notably fear of failure and desire for success Similar work is being done with dependency need affiliative needs and need for power A closely related line of work is illustrated by the researches of E Frenkel Brunswik on the authoritarian personality and the kinds of mechanisms that support such an orientation toward the social world namely intolerance of ambiguity as a cognitive and motivational characteristic

The field of personality research is growing at such a rate that it is difficult to foretell what shape it will take in the future Certainly th r is a tendency for the different approache to a e m nt to be joined together in more compreh n pro grams of a ment (a for exampl at the California Institute for Personality A e ment) It clear too that there is an increa g t nden y f r theorie f personality to le le *ad hoc* an l m r closely linked to principle of general p y h log e tal l hed in mo e c ntrolled exp r ment ti n (for example objective studi of p y h anal t mechan ms on th psychodyn mi s de the w rk *of G Kelly on the ide f tran f rmati n f s il y* e experience b c gniti e *proc* e l th w rk of J l iag t on child d l pm t and b the w rk of N E Miller and of F A B a l on l d mechanism) Finally it se m d t th t rail

Satellite motion is also disturbed by the direct attraction of other satellites, the Sun, and to a lesser amount by other planets. Observation of the orbital displacements caused by the mutual perturbations of satellites in the system of Jupiter and Saturn make possible the determination of the masses of these satellites. The solar attraction is significant in the orbits of the outer satellites of Jupiter and Saturn, reaching to one-ninth the planetary attraction for the eighth satellite of Jupiter. So greatly disturbed is this satellite that it is not possible to derive a general theory for its motion.

The orbit of the Moon is disturbed mainly by the Sun, with some changes in motion due to the oblateness of the Earth, the figure of the Moon, and small perturbations caused by the planets. The attraction of the Sun on the Moon is more than twice the Earth's attraction, but because both the Earth and Moon are free to move, it is only their relative acceleration with respect to the Sun which determines the motion. This relative acceleration toward the Sun is always less than 1/89 of the acceleration of the Moon toward the Earth. The eccentricity and inclination of the Moon's orbit oscillate slowly about their mean values, while the line of apsides advances with a period of almost 9 years and the nodes regress through one circuit in 18.6 years.

The observed motion of the lunar node and perigee afforded the means of determining the oblateness of the Earth, the lunar theory which best incorporates the value 1/298. The value of the flattening of the Earth adopted for the International Reference Ellipsoid ... [illegible] ... Recently measured motions of the nodes and apsides of artificial Earth satellites have ... oblateness of 1/298.3. Lunar ... perturbations of artificial Earth satellites ... orbits 500 miles above the surface ... with increasing distance from the Earth. Atmospheric drag ... significant ... how ... decreases with altitude. See CELESTIAL MECHANICS.

[R.L.D.]

Bibliography: J. A. Van Allen (ed.), *Scientific Uses of Earth Satellites*, 2d ed., 1958.

Perturbation (mathematics)

A modification ... in the mathematical structure of a problem, changing the problem from one that can be solved exactly, the unperturbed problem, to the perturbed problem for which the solution is ... only approximately. The methods employed for this purpose are ... perturbation theory. These methods attempt to ... the solution of the perturbed problem in terms of the ... of the unperturbed problem.

Examples. Examples of perturbation problems can be found in nearly every branch of mathematics and physics, and ... the latter ... PERTURBATION (ASTRONOMY). The simplest ... occur in ordinary algebra. Suppose that the roots of the equation $f(x) = 0$ are known (the unperturbed problem) and that the roots of the equation $f(x) + \epsilon g(x) = 0$ are to be found (the perturbed problem). The parameter ... measures the size of the perturbation. Another set of examples occurs in linear differential equations and in particle dynamics. Possible perturbations include changes in the forces considered to be acting on the particle as well as changes in initial conditions.

Several examples occur in partial differential equations. One physical realization occurs in the theory of wave propagation where the perturbations can be changes in the index of refraction, changes in initial conditions, or changes in the nature or shape of the surfaces encountered by the waves. All of these changes can occur separately or concurrently. The first of these changes is called a volume perturbation, the second a perturbation of initial conditions, the third a perturbation of boundary conditions. Similar examples can be taken from quantum mechanics, where the volume perturbation corresponds to a change in the Hamiltonian and perturbation of initial conditions to quantum mechanical time-dependent perturbation theory. *See* PERTURBATION (QUANTUM MECHANICS). Other partial differential equations of physics, such as the Laplace equation, the diffusion equation, and the equations of hydrodynamics, furnish further examples.

As a final illustration of the various types of perturbation, consider possible modifications in an equation (as well as boundary and initial conditions) describing the motion of particles such as neutrons or electrons moving through a medium which can scatter and absorb them. The equation is known as the Lorentz-Boltzmann equation and changes in it occur as a consequence of modifications of the laws of scattering and absorption that ... be ... of changes in the medium.

All of these problems are linear and can therefore be cast into an equation of the form $A\psi = \lambda\psi$, where ψ is the unknown quantity, λ is a constant, and A is an operator involving among other possibilities differentiation and integration. The quantity ψ may be a ... or a matrix quantity. When a solution can be obtained for only special values of λ, the eigenvalues, the equation is called the eigenvalue equation, and the associated problem the eigenvalue problem. The operator A contains the perturbation, that is, A equals $A + A$ where A is the unperturbed operator and A the perturbing term.

Iteration method. The method generally employed to obtain an approximate solution is called the iteration method. Rewrite the equation $A\psi = \lambda\psi$ as $(A - \lambda)\psi = -\epsilon A_1\psi$. Let the unperturbed solution be ϕ_0, where $(A - \lambda)\phi_0 = 0$. Then ψ_1, the first approximation to ψ, is obtained as a solution of $(A - \lambda)\psi = -A\phi$. A second approximation is the solution of $(A - \lambda)\psi = -A\psi$. The nth approximation is obtained in terms of the $(n - 1)$ approximation from the equation

Commensurable motions If the mean motion of the disturbed planet were exactly a submultiple say $\frac{1}{2}$ of the mean motion of the disturbing planet the maximum perturbation produced by their close approach would always occur in the same part of the disturbed orbit The displacement in position of the disturbed planet would increase with each coincidence until the character of the orbit became modified to the point where exact commensurability of the mean motions would cease to exist

Because the solar system is middle aged cosmically speaking few examples of commensurability of mean motions exist today None is found in the motions of the major planets Cases of near commensurability exist which give rise to long period periodic terms of large amplitude As an example the periods of Jupiter and Saturn are nearly in the ratio of 2 5 Thus after nearly 5 revolutions of Jupiter the two planets return to approximately the same juxtaposition Their line of coincidence however sweeps slowly around Jupiter s orbit completing a circuit in about 850 years and thus producing a perturbation of this period

Among the four inner planets the periodic perturbations are small amounting in orbital longitude at most to 25 for Mercury 5 for Venus 1 for Earth and 2′ for Mars Periodic perturbations of the outer planets are larger reaching in the case of the long period terms to 30′ for Jupiter 70 for Saturn 60′ for Uranus and 35 for Neptune

Because the amplitude of a periodic perturbation depends on the mass of the disturbing planet observational measurement of this amplitude affords a method of determining the disturbing mass For the planets Mercury Venus and Pluto which do not have satellites this is the only method of determining the mass As a consequence of the mutual perturbations of the planets the distance of a planet from the Sun is on the average decreased by the action of planets closer to the Sun and increased by planets farther from the Sun this mean effect represents a perturbation of the radius vector with a constant value

The orbits of the minor planets are affected in varying degree by the attractions of the major planets Those orbits passing close to Jupiter suffer large perturbation which if the mean motions were commensurable with that of Jupiter would be augmented at each close approach until the trajectories were sufficiently altered to reduce the commensurability In the over all distribution of mean motions of the minor planets there are noticeable gaps at the points where the period would be nearly an exact submultiple ($\frac{1}{2}$ $\frac{1}{3}$ [illegible]) of the period of Jupiter In cases of near commensurability observational determination of the amplitude of the long period perturbation affords a method for measuring the mass of Jupiter A small group of minor planets called the Trojan asteroids has been so completely captured by Jupiter that they oscillate about the 60 points which form equilateral triangles with Jupiter and the Sun See TROJAN PLANETS

Effect on comets Planetary perturbations also affect the orbits of comets Studies of the motion of Halley s comet indicate that the time from one perihelion passage to the next has varied by almost five years because of perturbations Most comets approach the Sun at nearby parabolic speeds in randomly oriented orbits but if a comet approaches close to one of the more massive major planets the planet may so alter the trajectory that the comet pursues an elliptical orbit thereafter A number of short period comets whose orbits agree only in that they all pass close to Jupiter illustrate the perturbing effect of this planet on cometary orbits

Nongravitational causes Material forming the tails of comets is subject to a nongravitational type of perturbation This rarefied matter given off by the head of the comet is forced into a trajectory away from the Sun by the pressure of solar radiation

Associated with many of the periodic comets are swarms of smaller particles which appear as meteors upon collision with the upper atmosphere of the Earth (*see* METEOR) The density of these swarms is so tenuous that they cannot hold themselves together by their own gravitation and planetary perturbations of speed and direction soon spread the components completely around the orbit The annual meteor showers such as the Perseids reflect this dispersal of particles along the orbit The effect of the Earth s attraction on a meteor trajectory depends on the relative velocity that is whether the Earth is overtaking the meteor or meeting it head on Once the meteor enters the upper reaches of the Earth s atmosphere its motion is subject to a nongravitational perturbation caused by atmospheric drag This resistance to the passage of the particle is evidenced by the trail of incandescent gas and vapor which forms until the particle is consumed or continues in its trajectory greatly decelerated

Perturbations of satellite orbits The motions of planetary satellites natural and artificial reflect both gravitational and nongravitational perturbations The centrifugal force arising from the rotation of a planet causes a deformation or oblateness of figure In such a case the central mass does not attract as if it were concentrated at its center For a close satellite the principal perturbation arises from the attraction of this equatorial bulge The effect of this attraction on an otherwise undisturbed satellite orbit is a gradual regression of the line of nodes on the equatorial plane and a rotation on the line of apsides Both rotations vary with the inclination of the satellite orbit Nearer to the primary the tidal force may become so great that a satellite would be literally torn to pieces For a fluid satellite of the same density as the planet the limit within which this disruptive perturbation occurs is about two and one half times the radius of the planet (*see* SATURN)

c n be employed a the init al appr ximat on ψ_0 n the iterati e method It i often the case that the determ at on of the p ss bl y is ffi ient fo th luati n f the major effects of the pe turb t on [H FE]

B bl ography P M Mor e a d H Feshbach M th d f Th ti al Phys cs 1953

Perturbation (quantum mechanics)

Pertu bati n te hnique a e ed n quant m me ch n in a tr nomy lass c l mech ni s and othe fields to btain approximate s lut on to pr bl m The a t majority f quantum mech n c l pr blems ca not b olved xa tly The tech iq e u d s num ro s nd matl em t cally tr c te only a few are des r bed here For b k g nd material se QUANTUM MECHA ICS QUAN TUM THEORY NONRELATIVISTIC Alth ugh the d s cu n he e confi ed t the d ma n of nonrelat t c quantum the ry where qu nt m pe t rb t th ory s co c rned alm t e clu ly w th olut ns t S hrod ge s eq ati n th re h b e mp rtant pplicati n t qua tum lectrody am s d qua tum fi ld theory S e QU NTUM ELECTRODYNAMICS QUANTUM FIELD THE ORY

In m y p ol l m Sch od ng r equat n has tl e f rm $H\psi = (H + \lambda V)\psi = E\psi$ the des r d g n alu $E(\lambda)$ a d ig f t on $\psi(\lambda)$ are n th d s cr t pect um and th c espond g $= E(0)$ nd $u = \psi(0)$ f ing the unpertu bed equ ti n $H_0 u = \epsilon u$ are kno n e a tly O as um s th t E nd ψ can be p d d as power ers s n λ b t tut s thes e (wh se oeffi ent a e st ll ndete m ed) to th S h od ge eq ti n and su r ly equat terms p port al to the am pow of λ sta t g w th λ Th p o d re succes i ely d te m nes the nknown c ff i nts n t rm of and u nd appe t e n tg best when

$$\lambda V' = (- \epsilon) \ll 1$$

wh r V $= j$ V re the m tr el ments of V th pe t rbed ep sentati n Th f nctio mu t be and can be chos o th t $V = 0$ wh n $\epsilon r \epsilon = \epsilon$ th t is th pe tu b t n mu t n t m rign lly deg e at tat th eq m t sel ts the t $= 1 m \psi(\lambda)$ as $\lambda \to 0$ fr m the many pos bl d g n te Th pertu b t n m thod is m pl ed for e ar ple to est mat the lev l spl tt n t th Zeem n ffect othe llust tio of t f ty nf rs th t as o i tm atom gy l f w th un qu onfigu at ns cf gle pa t cle states i m t l kely t be g od ppr mat on th t i l ast l kel t negl ct s r ous configu at n m g whe the i gl partcl f f e widely p ed

A s mila e pa ion i powers of λ is u d t ll on p blem I e $\psi(E) = (E) +$ $\lambda(E,\lambda)$ so ght wher th e tte d w λ t fi n a g d (u u lly th utg ng) b u d ary c d t th gy E s k wn and l es n th t uum whe e th level pact s z o th t th prev s p ocedu eq mod fi t on The term proportional t λ n the series expansion of λv yi ld the fir t Born approximation t the s att ring cro s ction the term r oportional to λ yields the e nd Born approximation etc The q ence of Born approximations appears to n erg be t when $\lambda V/E \ll 1$ that i wl n th in cident ki etic ene gy is high excepti ns to this rule d o cur however esp cially in many particle collisi n See SCATTERING EXPERI IENTS ATOMIC AND MOLECULAR SCATTERI G EXPERIMENTS NU CLEAR

Th WKB (Went el Krame s B illou n) method sub titutes $\psi = A \exp(2\pi i W/h)$ into Schro dinge quat on and a sumes A W ar expans ble in p wers of h In z r th appr ximation as $h \to 0$ tl pha e W s t fies the Hamilton Jacobi equation d mon trati g the connection between cla s cal a d quantum mechan cs (s e HAMILTON JACOBI THEORY) The p actical i tility of the next (WKB) appr ximation giving the quantal correc ti i t the class al limit $h = 0$ almo t exclu si ely confi ed to one-d me onal problems the WKB approximati n is best when $d|\lambda|/dx \ll 1$ where $|\lambda(x)| = h/|p| = h[2m|E - V|]$ / i th ma n ude of the lo al de Br gl wa elength For t nuum e genfunction the WKB approximation y elds estimates of the penetrability f a barrier nd of th pha e shift n catteri g problems For bound tate g nfunct o the WKB appr xim ti n y elds a corrected r ion f the pre-Schro d nge q antizat n rule $\oint p\,dx = nh$

The for going methods perta to time nd p nd e t problems When the pert rbat n is a t me-de pend t nter ction $V(t)$ one sually wishes to ompute the t ansiti ns which V indu e fr m i t al stat a y tat u of H t final st tionary tat s u_f Th sudden appr ximat on is adapted to potenti ls $V(t)$ wh h ch nge during a br f i terval Δt nd appears to be valid when $\omega_f \Delta t \ll 1$ whe e $\omega_f = h(E_f - E)$ a e the rcul r f equenci a ociated w th the poss bl tr n it on $i \to f$ Th appro im t on useful for x mple t d termin the p bability that adio- ti e de ay f a H tom will yi ld a do bly i n zd He o F r slowly hanging potential $(\omega_f \Delta t \gg 1)$ the di batic pprox mat o which s ppo th t di ete quantum numbers cha te zing the itial w ve functi rem in c nstant the pot t al cha g s often eful Se PERTURBATION (ASTRONOMY) PERTURBATION (MA HEMATICS) [E C]

B bl g phy S e QUANTUM MECHANICS QUAN TUM THEORY NONRELATIVISTIC

Pesticide

A material n ed to c trol in ct, d s a d weed pe ts whi h au e s gnific nt l es in gr c lture Cr p lo s th Un t d States cau d by insects di ea e nd weeds h v been e tim ted to tot l m r than $12 000 000 000 ann lly Thi lo rep es nts app matcly one-thi d th t tal annu l l e of griculu l p od cti n n th Un t d State S AGRICULTURAL CHE ISTRY Ac

$A_0 - \lambda_1)u_n = -\epsilon A_1 u_{n-1}$. It is assumed that the properties of the unperturbed operator, A_0, are sufficiently known so that the solution of these equations can be obtained. If the sequence of u ... u converges, it will converge to a solution of the problem. For an eigenvalue problem, the procedure must be modified. The first approximation to λ is λ_1, the nth approximation is λ_n. Then the equation determining u_n in terms of u_{n-1} is $(A_0 - \lambda_{n-1})u_n = -\epsilon A_1 u_{n-1}$. It is important for the practicality of this procedure that the approximation λ_n can be expressed in terms of the approximation u and the operators A_0 and ϵA_1.

In a related and more familiar formulation both u and λ are expanded in a power series in ϵ, that is, $u = \phi_0 + \epsilon\phi_1 + \epsilon^2\phi_2 + \cdots$ and $\lambda = \lambda_0 + \epsilon\lambda_1 + \lambda_2 + \cdots$. Then the equation $A_0 u = \lambda u$ reduces to a set of equations for ϕ_n. For example, the equation for ϕ_1 is $(A_0 - \lambda_0)\phi_1 = -(A_1 - \lambda_1)\phi_0$ and the equation for ϕ_2 is $(A_0 - \lambda_0)\phi_2 = -(A_1 - \lambda_1)\phi_1 - \lambda_2\phi_0$, and so on. This formulation is more complex, and often yields slower rates of convergence than the method just outlined.

The iteration method can be generalized in two respects. First, it is not necessary to use u_0 as the zeroth approximation to u. If by reason of other information, a better approximation, say u_1, is known, the iteration sequence starts with the equation $(A_0 - \lambda)u_2 = -\epsilon A_1 u_1$. Second, the iteration method can be employed in the treatment of nonlinear as well as the linear problem discussed in detail here.

For the iteration method to be at all useful, it is necessary for the sequence u ... to exist and to converge. The usefulness of the method increases with increasing rate of convergence. The convergence ... of the singularities of the perturbation are not too strong, or if the initial zero approximation is wisely chosen ... When the sequence exists, it will converge for a range in values of the parameter ϵ. The largest value of ... is the radius of convergence. This is found to be the value ... for which the equation $A_0 u = \lambda$ ... has at least two degenerate solutions, that is, solutions with identical values of λ. There are various methods of increasing the rate of convergence. For example, the general techniques of analytic continuation such as the Euler transformation can often be employed. A clever choice of the zero approximation will often yield the desired effect. This general method can ... the ... A more general result was derived ... for the solution of $A u = \lambda$ ... is ... the ... of ... function ... each of which can be expressed as a series ... the ... of these series will have an infinite radius of convergence.

The eigenvalue problem can be reduced to the problem of the solution of a set of homogeneous linear simultaneous equations, which in general ... always ... a nontrivial solution of ... equations ... will ... all the determinant of the coefficients is zero. Because the coefficients involve the eigenvalue λ, this condition ... an equation, the secular equation, which determines the possible values of λ. The determinant is known as the secular determinant. An example follows. Let the solution of the unperturbed problem be $\phi^{(r)}$ with eigenvalues $\lambda^{(r)}$, that is, $A_0\phi^{(r)} = \lambda^{(r)}\phi^{(r)}$. Moreover, suppose that the set $\phi^{(r)}$ is complete, which roughly means that an arbitrary function can be represented as a linear combination of $\phi^{(r)}$. Therefore let u, the solution of the perturbed problem, be $C_1\phi^{(1)} + C_2\phi^{(2)} + C_3\phi^{(3)} + \cdots$, where C are constants. By substituting this expression for u into the equation $A u = \lambda u$ and employing the properties of the set $\phi^{(r)}$ which follow from the nature of the operator A_0, one can obtain a set of equations for C_p. In a typical case these equations have the following form

$$C_1(\lambda - \lambda^{(1)}) - C_1(\epsilon A_1)_{11} - C_2(\epsilon A_1)_{12} - \cdots = 0$$

$$C_1(\epsilon A_1)_{21} - C_2(\lambda - \lambda^{(2)}) - C_2(\epsilon A_1)_{22} - \cdots = 0$$

$$C_1(\epsilon A_1)_{31} - C_2(\epsilon A_1)_{32} - C_3(\lambda - \lambda^{(3)}) \cdots = 0$$

and so on. The elements $(\epsilon A_1)_{pq}$ are numbers which depend upon $\phi^{(p)}$, $\phi^{(q)}$, and the operator ϵA_1. The consequent secular equation is obtained by setting the determinant of the coefficients of C in this sequence of equations equal to zero. The solution of these simultaneous equations for the coefficients C can be obtained by the iteration method, which yields a particular representation of each of the approximations u_n. If there are only a finite number of C_p, the secular determinant is of finite order and reduces to a finite polynomial in λ, so that in the finite case the solution of the secular equation can always be obtained without resort to perturbation methods. Once the allowed values of λ are known, the corresponding values of C can be determined.

Degenerate perturbation theory. A special technique is required when the unperturbed problem is degenerate, that is, when there are several solutions of the equation $A_0\phi = \lambda\phi$ for a single value of the eigenvalue λ. The number of such independent solutions is the order of the degeneracy. The corresponding methods are designated degenerate perturbation theory. The objective of the special method adopted for this case is the determination of the proper linear combinations of these degenerate solutions for use as the zeroth approximation u_0 in the iteration method. To this end all terms in the equations for C are dropped which refer to an unperturbed solution which is not one of the degenerate solutions under consideration, and all those C which do not refer to these degenerate solutions are assumed. The resulting secular equation for λ has a number of roots equal to the order of the degeneracy. For each root there is a corresponding set of values for C which determine a particular linear combination of the degenerate unperturbed solutions. Each of these combinations

can be employed as the initial approximation ψ_0 in the iterative method. It is often the case that the determination of the problem is sufficient for the evaluation of the major effects of the perturbation. [H FE]

Bibliography P M Morse and H Feshbach *Methods of Theoretical Physics* 1953

Perturbation (quantum mechanics)

Perturbation technique as used in quantum mechanics ... in astronomy ... classical mechanics and other fields to obtain approximate solutions to problems. The great majority of quantum mechanical problems cannot be solved exactly. The techniques used are numerous and mathematically intricate; only a few are described here. For background material see QUANTUM MECHANICS, QUANTUM THEORY NONRELATIVISTIC. Although the discussion here is confined to the domain of nonrelativistic quantum theory where quantum perturbation theory is concerned almost exclusively with solutions of the Schrodinger equation, there have been important applications to quantum electrodynamics and quantum field theory. See QUANTUM ELECTRODYNAMICS, QUANTUM FIELD THEORY.

In many problems Schrodinger's equation has the form $H\psi = (H + \lambda V)\psi = E\psi$; the desired eigenvalues $E(\lambda)$ and eigenfunctions $\psi(\lambda)$ are, in the direct perturbation approach, the corresponding $E(0)$ and $u = \psi(0)$ of the unperturbed equation $H_0 u = \epsilon u$ are known exactly. One assumes that E and ψ can be expanded as power series in λ; substitutes these series (which ... fficients are still ... ned) into the Schrodinger equation and successively equates terms proportional to the same power of λ ... This procedure successively determines the unknown coefficients in terms of ϵ and u and appears to converge best when

$$\lambda V' (\ - \epsilon)^{-} \ll 1$$

... $=$ ... V' are the matrix elements of ... in the ... perturbed ... presentation. The ... can be chosen so that ... $= 0$ wh ... th ... the perturbation mixes states ... states ... which ... $= \lim \psi(\lambda)$ as $\lambda \to 0$ from the many possible ... This perturbation method has employed ... example ... estimate the ... splitting in the Zeeman effect ... other illustration ... the ... configuration energy ... with unequal ... figu ... single particle states, most likely to be good approximations; ... least likely to neglect serious configuration mixing, which the single particle ... widely ... pared.

A similar ... pa sion in powers of λ ... ed ... problems ... $\psi(E) = u(E) + \lambda \ell (F,\lambda)$ ... sought where the scattered wave ... λ ... at ... (... lly the outgoing) boundary ... the energy E is known and ... the ... where the level pairing ... so that the previous procedure requires modification.

The term proportional to λ in the series expansion of λv yields the first Born approximation to the scattering cross section; the term proportional to λ yields the second Born approximation, etc. The sequence of Born approximations appears to converge best when $\lambda V /E \ll 1$, that is, when the incident kinetic energy is high; exceptions to this rule do occur however, especially in many particle collisions. See SCATTERING EXPERIMENTS, ATOMIC AND MOLECULAR; SCATTERING EXPERIMENTS, NUCLEAR.

The WKB (Wentzel-Kramers-Brillouin) method substitutes $\psi = A \exp (2\pi i W/h)$ into Schrodinger's equation and assumes A, W are expandable in powers of h. In zero-th approximation as $h \to 0$ the phase W satisfies the Hamilton-Jacobi equation, demonstrating the connection between classical and quantum mechanics (see HAMILTON-JACOBI THEORY). The practical utility of the next (WKB) approximation, giving the quantal correction to the classical limit $h = 0$, is almost exclusively confined to one-dimensional problems. The WKB approximation ... best when $d\lambda/dx \ll 1$ where $|\lambda(x)| = h/|p| = h[2m(E - V)]^{-1/2}$ is the magnitude of the local de Broglie wavelength. For ... the WKB approximation yields estimates of the penetrability of a barrier and of the phase shifts in a scattering problem. For bound state eigenfunctions, the WKB approximation yields a corrected version of the pre-Schrodinger quantization rule $\oint p\,dx = nh$.

The foregoing ... pertain to time-independent problems. When the perturbation is a time-dependent interaction $V(t)$, one usually wishes to compute the transition which V induces from initial stationary state ... of H to final state u_f. The ... approximation is adapted to potential $V(t)$ which change during a brief interval Δt and appears to be valid when $\omega_f \Delta t \ll 1$ where $\omega_f = h (E_f - E)$ are the circular frequencies associated with the possible transitions $\to f$. This approximation is useful for example to determine the probability that radioactive decay of a H ... atom will yield a doubly ionized He ion. For slowly changing potentials ($\omega \Delta t \gg 1$) the adiabatic approximation, which supposes that discrete quantum number characterizing the ... wave function remain constant as the potential changes, often is useful. See PERTURBATION (ASTRONOMY); PERTURBATION (MATHEMATICS). [E C]

Bibliography See QUANTUM MECHANICS; QUANTUM THEORY NONRELATIVISTIC.

Pesticide

A material used to control insect, disease, and weed ... p ... which cause significant losses in agriculture. Crop losses in the United States caused by insects, diseases, and weeds have been estimated to total more than \$12,000,000,000 annually. This loss represents approximately one-third the total annual value of agricultural products in the United States. See AGRICULTURAL CHEMISTRY; AGRICUL-

TURE FUMIGANT FUNGISTAT AND FUNGICIDE HERBICIDE INSECTICIDE MITICIDF NEMATOCIDE RODFNTICIDF [C A H O D]

Petrifaction

One of the most remarkable mechanisms by which the remains of extinct organisms are pre erved in the fossil record is the process of petrifaction In petrifactions though chiefly in the ca e of plants rather than animals there is retained relatively undeformed the original shape and topography of the ti sues and occa ionally even minute cytologi cal details

Formation The term *petrifaction* was adopted as a scientific term before knowledge existed of the geochemical mechanism or processes in olved It was formerly widely believed that in the formation of a petrifaction the organic matter of the organism or ti ue involved was replaced molecule by mole cule with mineral material entering in solution in percolating ground water It is now evident that what actually happens is that the mineral fills cell lumens and the intermicellar interstices of cell walls with insoluble salts depositing from solution Petrifaction is hence a form of mineral emplace ment or embedding by which the organic residues are filled with solid substance which infiltrate in olution The most common substances in olved in petrifactions are silica SiO_2 and calcium car bonate $CaCO_3$ (calcite) Occasionally phosphate minerals pyrite and hematite and other less com mon minerals comprise all or part of the petrifac tion matrix The most perfect preservation of orig inal structure is found in siliceous petrifactions The clear transparent or microcrystalline silica renders excellent optical properties to thin sections of such fossils and makes possible the use of trans mitted light in microscopic study in much the same manner as with recent biological material

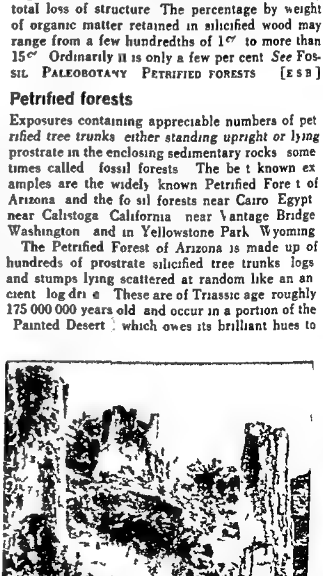
Calcified types An unusual type of calcareous petrifaction known as coal balls occurs in Carbonif erous coal seams of parts of Europe and North America They comprise nodular usually spheroidal or ovoidal mas es of relatively uncompressed plant tissues completely permeated with calcite or dolo mite They represent irregularly spaced and local ized areas of mineral precipitation with esulting petrifaction of the coal forming plant deb is Min eralization occurred while the coal was still in the peat stage After mineralization the plant parts so infiltrated failed to compre s so that their structure and cellular organization are preserved Much of what we know of the internal organizati n and anat omy of ancient pl nts and e olution of the r o ans both vegetative and reproducti e is de ed from petrifactions which occur throughout the geo logic record from P ecambrian to recent Coal balls though limited to the Carboniferous have provided an unusually comprehensi e body of knowledge on the morphology and anatomy of the rich and aried vegetation of this unit of geolog c time *See* COAL BALLS

Silicified types De pite the widespread abun dance of petrifactions (chiefly of plants but also of the hard parts of animals) throughout the geo logic column there is very little known of the geo chemical mechanisms which induce their formation The problem is particularly baffling in the case of silicification in many examples of which entire trunks of trees may become completely mineralized *with no vi ible evidence of the sequence of changes* following sedimentation The fact that silicified plant parts often how virtually no physical dis tortion or compression indicates that the process occurs relatively rapidly On the other hand the amount of silica in ground water (±70–100 parts per million) is so small that the process must *proceed with extreme efficiency* It is probable that decay processes must have proceeded to at lea t the early stages since the histology of silicified (al o calcified) plant tissues exhibits varying stages of degradative alteration to the extremes of nearly total loss of structure The percentage by weight of organic matter retained in silicified wood may range from a few hundredths of 1% to more than 15% Ordinarily it is only a few per cent *See* FOSSIL PALEOBOTANY PETRIFIED FORESTS [E S B]

Petrified forests

Exposures containing appreciable numbers of pet rified tree trunks either standing upright or lying prostrate in the enclosing sedimentary rocks some times called fossil forests The be t known ex amples are the widely known Petrified Fore t of Arizona and the fo sil forests near Cairo Egypt near Calistoga California near Vantage Bridge Washington and in Yellowstone Park Wyoming

The Petrified Forest of Arizona is made up of hundreds of prostrate silicified tree trunks logs and stumps lying scattered at random like an an cient log dri e These are of Triassic age roughly 175 000 000 years old and occur in a portion of the Painted Desert which owes its brilliant hues to



Up ght p t f d t ee Sp m Rdge Y ll w t N t l P k Wyom g

the ar colored layers of the Chinl formatı n The wood s mai ly agat zed or changed t cl alced ny and h w a unusu lly a ed a d b aut f l col ra n of ed br wn y llow a d purpl s The maj r ty of the p trified tr es are Con fe s (*A au ca ı xylon*) d tantly rel t d to th a auca an pı n of South Am ı and Au t al a One huge log o er 100 ft lo g ha been left by er n cr ss a r ı bout 40 ft w de f rm ng a natural pan kn wn s Agat Bridge Here a d th e are expo- s e of sh le beds c nt ı ıng many ımpr on f le s and seeds rep esent ng a humıd subtropı al f est bo d r ng the st n ms f a lowl nd a anna

An eve mo e e te e fo ıl f rest lı s ın the rthea t rn p rtion of Yellow t ne Natı nal Park Wy mı g He e the major ty f the pet ıfied t ee t u k are f und still tand ng upr ght ın p sıtions of or gın l growth ın th enclo ı g med um of ol ca c tuffs and bre c a Even more unu al ıs the occ rr nce here of n t merely a ıngle f ıl fo e t but a ert cal s cce s on f o er 20 burıed f rests —one abo e the other—ın a thıckne s of ov r 2000 ft of olca c debrı The fos ılızed trees and the ımpres on of lea es, twigs needles and co es ın as oc ated ash laye s ındıcate a f r t of o r 100 spec n of warm tempe at to subtr p c l t ee typ c l of a h mıd lowl nd envır ment. *See* PA LEOBOTANY ee ls VEGETATION ZO ES [E D]

Petrochemical

O e f l g numbe of b tant llv p m hem al ub t e p odu ed omm r ıally f m p tro- le m r tural g Ord na ly the term d e n t n lude hyd o rt n fuels a d l b c nts n r chem als prod ed by the s tha the p e or ha dl g th p t leum raw mate l S PETRO- LEUM P ODUCTS O g n ompound mp ı e the g at l tk a w ll as n mbe f pet ochemı l but e al g n c e mp unds (amm car bon bla k ulf and hyd ogen p rox de) also are p od ed n l ge am t

Thu pet ochem cals a e n t t be reg rded a a p rt la type r l s of hem cal c all of th m h n bee d many t ll re mad f m other raw m te ı l f ex mpl b n e and tyle fr m l gl) r l fr m fat ethyl lco- h l f m ag ultu l p and s lfu f m de- pos t f the lement r fr m met l ores

Some h m l n mad from the raw ma t al ar now m d ent l alm t e t rely f m p t l m t r l g Examples a e a t g n lly d ed f m w od d ı ll t on and lat hy f rm t t f g ult r l produ t th l h l d r g ll m d f m thyl al oh l p od ed by f rm t t n d b tad n mad f m th l l h l d g W ld War I a d s a ı g W ll Wa ll l ı 1946 d r ed almo t mpl t ly f m pet l m

P troch m al l d al m n p dı cts never bef kn w ex pt f l br t r m unt h ll l chl l all l lcoh l pı hl hydr n m thyl l tyll t nd a l t

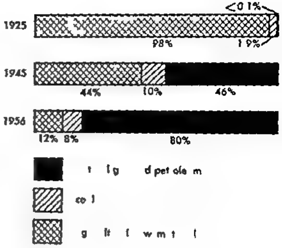


Fig 1 S e f rg c ch mc l l the U ited St tes

Growth and present size The over all trend to petroleum and natural gas as the predominant source of organ c hemicals ın the United States ıs shown ın Fig 1 Two of the ıno ganıc petrochemı cal (ammonıa and carb n black) also domınate the r respectı e fi lds

Over 40 000 000 000 lb f petrochemicals are p duced an u lly about 27% f the tot l cl em cal p ductıon ın the Unıted States (orga ıc and ın ga c) a d from ne thı d to ver ne-half of ts t tal dolla value d pend ng upon th b ıs sed P t hemıc ls m n fa tured ın the Un t d States make up o er 8 of all lıphat cs 10% of all n rg ı s and 54% of ll a omatı About 3% of all c ude ıl u d n the Un ted St te ıs u ed as petr h t al fe d tock

Th re w r no pet ch m cals befo e 1920 as de from carb n bl ck which h been mad ın the Un ted States f m nat ral ga ın e 187 The g owth of petr ch mı al sınce 1920 (Fig) has b en mo t p ctacular ın th f ld of al phatı wh ch a count f r well o e l alf of th pres nt to- t l olume of petroch m cals a d by fa th l rge t numbe of th n a l 3000 pet ochem cal de ed compo nds n w p duced This growth ı due ma nly to the following fi e f ct r

1 The ab ndan e and latı ely low o t f c ud l and natu l g

2 Ad anc s made ın the t hnol gy of petro- leum refinı g spu ed e pec ally by the demand f r m tor ga l ne nd v atıon ga ol e The e ın l d mo e effi nt fractı nal d ıllat n and other ep n tıon proc s es part cul ly fo the lower b ıl ng e st t nt and the d elopment of con er p oces e to ne ease ga ol ne quantıty and q al ty nclud g thermal a d cat lyt crack ng hyd ogenat on d l yd og tıor p lymerızatı n ı zat n a d alkyl t on Th e eparat n and n n proces es ha e m d a ail ble as by prod ha e b en r dıly adapted t th tentı l p oductı n f la quantıtı f ınd d u l hyd oca bon o mpl mı tu quıte su table a h mı l w mat r l

TURE FUMIGANT FUNGISTAT AND FUNGICIDE HERBICIDE INSECTICIDE MITICIDE NEMATOCIDE RODENTICIDE [C A H O D]

Petrifaction

One of the most remarkable mechanisms by which the remains of extinct organisms are preserved in the fossil record is the process of petrifaction In petrifaction though chiefly in the case of plants rather than animals there is retained relatively undeformed the original shape and topography of the tissues and occasionally even minute cytological details

Formation The term petrifaction was adopted as a scientific term before knowledge existed of the geochemical mechanism or processes involved It was formerly widely believed that in the formation of a petrifaction the organic matter of the organism or tissue involved was replaced molecule by molecule with mineral material entering in solution in percolating ground water It is now evident that what actually happens is that the mineral fills cell lumena and the intermicellar interstices of cell walls with insoluble salts depositing from solution Petrifaction is hence a form of mineral emplacement or embedding by which the organic residues are filled with solid substance which infiltrate in solution The most common substances involved in petrifactions are silica SiO_2 and calcium carbonate $CaCO_3$ (calcite) Occasionally phosphate minerals pyrite and hematite and other less common minerals comprise all or part of the petrifaction matrix The most perfect preservation of original structure is found in siliceous petrifactions The clear transparent or microcrystalline silica renders excellent optical properties to thin sections of such fossils and makes possible the use of transmitted light in microscopic study in much the same manner as with recent biological material

Calcified types An unusual type of calcareous petrifaction known as coal balls occurs in Carboniferous coal seams of parts of Europe and North America They comprise nodular usually spheroidal or ovoidal masses of relatively uncompressed plant tissues completely permeated with calcite or dolomite They represent irregularly spaced and localized areas of mineral precipitation with resulting petrifaction of the coal forming plant debris Mineralization occurred while the coal was still in the peat stage After mineralization the plant parts so infiltrated failed to compress so that their structure and cellular organization are preserved Much of what we know of the internal organization and anatomy of ancient plants and evolution of their organs both vegetative and reproductive is derived from petrifactions which occur throughout the geologic record from Precambrian to recent Coal balls though limited to the Carboniferous have provided an unusually comprehensive body of knowledge on the morphology and anatomy of the rich and varied vegetation of this unit of geologic time *See* COAL BALLS

Silicified types Despite the widespread abundance of petrifactions (chiefly of plants but also of the hard parts of animals) throughout the geologic column there is very little known of the geochemical mechanisms which induce their formation The problem is particularly baffling in the case of silicification in many examples of which entire trunks of trees may become completely mineralized with no visible evidence of the sequence of changes following sedimentation The fact that silicified plant parts often show virtually no physical distortion or compression indicates that the process occurs relatively rapidly On the other hand the amount of silica in ground water (±70–100 parts per million) is so small that the process must proceed with extreme efficiency It is probable that decay processes must have proceeded to at least the early stages since the histology of silicified (also calcified) plant tissues exhibits varying stages of degradative alteration to the extremes of nearly total loss of structure The percentage by weight of organic matter retained in silicified wood may range from a few hundredths of 1% to more than 15% Ordinarily it is only a few per cent *See* FOSSIL PALEOBOTANY PETRIFIED FORESTS [E S B]

Petrified forests

Exposures containing appreciable numbers of petrified tree trunks either standing upright or lying prostrate in the enclosing sedimentary rocks some times called fossil forests The best known examples are the widely known Petrified Forest of Arizona and the fossil forests near Cairo Egypt near Calistoga California near Vantage Bridge Washington and in Yellowstone Park Wyoming

The Petrified Forest of Arizona is made up of hundreds of prostrate silicified tree trunks logs and stumps lying scattered at random like an ancient log drive These are of Triassic age roughly 175 000 000 years old and occur in a portion of the Painted Desert which owes its brilliant hues to

Up ght p t f d t Sp c m Rdg Y ll w t N t l P k Wyom g

the v l red lay rs of th Ch le fo m t on The ood ı ma ly ag tized r cha ged to halcedony a d h ws a n u lly d and beautiful col a t of red B wns yellows and p rples Th m ȷ rity of the p t fied t ees are Conife s (*A u c roxylo*) d t tly l ted to the a c ria p es f So th America and Au tralia One h ge l g ≡ 100 ft l g h b l ft by e s n ac s bo ı 40 ft wide form g a n t ral p k wn s Ag te Bridge II ≡ d the e are expo- s f shal beds t g ma y imp so f l es a d seed ≡ esenti ≡ hum d subtrop l f est borde g the stream of a lowl d avanna An eve m e e t ı e fo l f est l e n the rtheastern p rti f Yellow to e Nat l Park Wy ming Here th majority of th pet ified t ee tr k are f d t ll sta d g upright in p itio s of o ≡ nal growth the closi g med um of l nic t ff d b e cia E en mo e u sual the occurrence h re of not me ely a single fos l fore t b t a ertical successi n of e 20 bur d forests —o ≡ abo the other—in a thickness of o er 2000 ft of olcan deb s The f ssil ed t ees a d the imp ı ns f lea es twig needles nd cone in a soc ted a h laye s d te a f rest of ve 100 pecies of w rm temperate to subtrop al tre s typ al of a h mid lowla d e ı me t. *See* PALEOBOTANY *s e l* VEGETATION ZONES [E D]

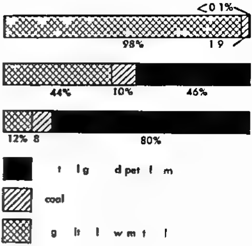
Petrochemical

O f a l g n mber f bst nt lly p e chem cal s b t e prod ced c mm ≡ lly f m petrole m at r l g O d ily the t rm d s n t ı l d hyd arbo f el a d lub ı ts or ch m l p od ed by th r th n the p oces r h dl g th p t le m aw m te al *S e* PETROLEUM PRODUCTS O g mp ds c mp th g t b lk w ll as n mber of p t och m l b t sev l n g mp und (amm n ca bo bla k lf d hyd gen p o d) ls are prod d l rge m nt

Thu ≡ t ochem l a e not t b reg ded a p rt cul r typ cla f ch m c l s ce all f th m ha been a d ma y st ll a e m de f m th w m t l f e mple be e ≡ d tyl e f m l glyc l f m f ts ethyl al o- h l f m gri lt l p d ulf f om d po t f th l me t r fr m metal o es

Som hem l on e made f m the r w m t l w m d ı ely lm t e t ely f m pet le m r ≡ al g E amples re t ≡ lly d ed f m ood d t ll t nd lat h f rm t t f g c lt r l p od cts th l hl d g lly mad f m thyl al h l p od ed by f m tat nd but d e e m de f m th l l h l d g W ld W r l d ı pg p m bo t h lf f m thyl l h l d g W ld W ll b t 1946 de ed lm t mpl t l f m pet lei m

P t och m l l d l m ny p od t eve bef k wn pt l bo at ry m ts, u h sop pyl l h l th l d gl l the ll l hl d ll l l h l p hl hyd m thyl l tyl ket d ı



Fg 1 So f g ic ch m l l the U t d St t s

Growth and present size The o er all trend to petroleum and n tur l gas as the predomi ant so rce f organ c chemical in the United States is hown in Fig 1 Tw of the ino ganic petrochemi cals (mmon a d arbon black) also dominate their e pect e field

Over 40 000 000 000 lb f pet ochem cals are prod ced a n lly about 27% of the tot l chemi al p odu t n in the United St te (g nic and g c) d fr m ne th d t o er ne half f its t tal d ll l depe di g p n the bas s ed Petr ch m cals ma uf ctur d ı the Un ted States make p o 85% f ll liphati s 10% of ll n g n s nd 54% of all a omatics About 3% of all crude l sed in the U t d State ı u ed s p tr chem c l f ed t k

Th e we e n petr chemi als before 19 0 a de f om ca b n bl ck whi h h s been made in the U it d St te from atur l ≡ s since 1872 The growth f pet ochem ≡ ls in e 1920 (F g 2) h s b e m t spe tac la in the field f liph ti s whi h a c t fo w ll o er h lf f the p ent to- t l olum f pet ochemi al nd by far the la ge t umbe f th nea ly 3000 petr hem al deri d ompo d w p od ced Thi growth ı d e ma nly t the f ll wi g fi e fact rs

1 Th ab d and elati ely l w cost f rud l a d atu al ga

2. Ad an e made in the te h ology f pet o- l m refi g purr d espe lly by th dema d f m t g s l e a d a at n g l ne These n l de mo ffic e t f t on l d st llati nd the s pa t p oce es part ularly for the l we bo li g e st tu nts d th developm nt f n proces es t ı e gas l ne q antity and quality cl d g th rm l d c talytic cracki g hyd og ati dehyd gen ti polyme izati n ı m zati d lkylati Thes sep t n nd c p oce ses h e m d a lable s by p od cts h e b e ead ly d pted t th t t al pr d t f l rg q ant t es f ı di d l hyd oc bo mple m xt res q t u t ble h m l w m t l

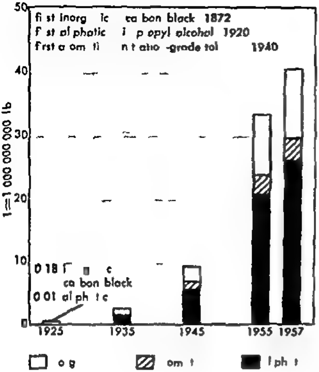


Fig 2 Growth of petrochem cals p oduct on the Un t d States

3 *A demand for chemicals that in many cases* could not be supplied in sufficient amounts or with sufficient assurance of a steady supply and price *structure from other sources*—coal wood or agri cultural products

4 Concentration of end uses in the relatively young and more rapidly expanding sectors of the economy for example automotive and aviation chemical products such as antifreeze and anti knock compounds and brake fluids synthetic fi bers plastics and resins and protective coatings

5 Research mindedne s leading to products not before known commercially (ome of which have *found extensive use) also to lower cost proces es* for established products often greatly expanding their application A special characteristic of petro chemical research has been the de elopment of a serie of related deri atives from the primary pet rochemicals in rder to establish the widest possi ble market

Raw materials and products The major opera tions of the petrochemical industry are summarized below for each of the principal raw materials In addition to the products shown large numbers are made in smaller amounts

Natural gas varies widely in composition but *consists predominantly of* methane with succe sively maller amounts of higher paraffin hydrocar bons Hydrogen sulfide carbon d xide and ni trogen are sometimes present The principal petrochemicals deri ed from natural gas or its methane content are hown in Fig 3 and Table 1

Inorganic petrochemicals Ammon a is by far the largest volume petrochem cal and natur l gas methane is by far the large t source of the hydrogen although hydrogen from refinery sources such as catalytic reforming is growing in u e A large proportion is converted into ammonium nitrate and other ammonium salts and into urea The largest use of the as of ammonia it elf is as fertilizer

Carbon black is made almo t entirely by partial combustion with insufficient air upply using natu ral gas in the old channel proce s and either natu ral gas or highly aromatic petroleum oil in the newer furnace process The latter proce s (ac counting for about 75% of the carbon black pro duction) gives a product suitable for use in syn *thetic rubber See* CARBON BLACK.

Aliphatic organic compounds Methane is the chief ource of methanol and hydrogen cyanide *and an important source of chloromethanes and* acetylene

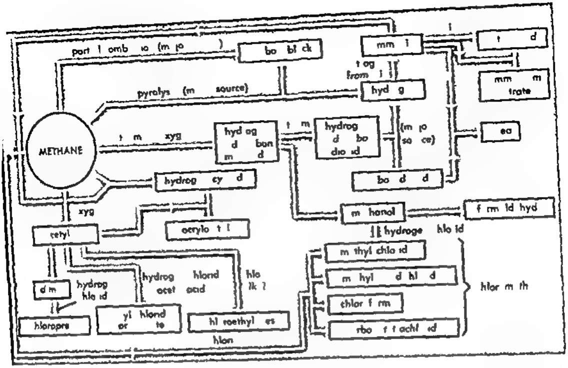
Paraffin hydrocarbon raw materials heavier than methane are mainly ethane propane butane and pentane The first two especially ethane are cracked thermally in large quantities to produce ethylene (and propylene) a di cus ed below Propane is also nitrated commercially to a mixture of nitroparaffins which ha found mall cale u e as olvents Propane and butane are oxidized di rectly in fairly large amounts to formaldehyde and acetaldehyde with minor amounts of other oxygen ated hydrocarbons Small amounts of pentanes are *chlorinated* the chloropentanes are con erted into substances such as amyl alcohols and amyl ace tates

Ethylene is consumed in larger amounts for ali phatic petrochemicals than is any other hydrocar bon (about 4 000 000 000 lb/year) About half comes from refinery thermal and catalytic cracking ope ations conducted primarily to increa e the

Table 1 Pet ochem cals from meth n

B d n es d sou ces	Prod d lly $\times 10^6$ lb	Uses %
Amm P tr l m so es M h h droge 79% R fi ry h droge 4% Elect lyt co l 17%	6600	Agr l t m l (mm salts) 6 Fibers pl cs 6 I d l plos es 5 Oth 6
C bo bl k N l ga ~50% L q d pe rol m ~50%	1800	R bbe compou d g 96 Pigm ts in tall gy 4
M th l P trole m sou ces M h 63% Propa e-b ta 7% Coal 30%	1700	F rm ld hyd (m ly f es) 36 M h nol free 6 Ethyl l col Oth 49
Chlorom tl es M th hlori t 50% Oth sou ces 50%	500	Sol l m bl fl orca bo f f gera rosol
Acet l P l m (m ly m h) ~3 % Calci m b d bal ce	640	V l hlor d yl ceta 30 Chloro re (eo- pr) 6 Chloroe h l es 1 Acr l l 8 O h 4
Hydroge cy d D t. f Comm ce d ta p po t from m h p bably >70%	~150	Acrylon t l (w h th l d or yl) 6 Ad po l 7 O h 11

La est fig es l bl



Fg 3 P t h m l f m m th

q t ty d q l ty f g l e p d d nd the rest c m m ly f m th ra k g of p p n d th e Th pr p l petr hem l de ed f m th l e re h w i Fg 4 a d T ble 2

Alte at t f m ngle p t le m d t l g t ta h m l e all t ted Fg 3 (bo bla k mm methyl hl id) a d Fg 4 (eth l de ethyl al o- h l) Alt t e pet l m sour es a ll tr ted th l l hl de d ryl n t il c r tl e p od ed mm lly f m b th ety l d th l e D t l g p at ll s- t t d Fg 3 by tle ynthe f u ea u ing l d d p d ed w th th hyd g n e q ed f th mm nd T bl 2 by th p o- d t d m lt eou til zat n f hyd og hl d th m f t e f thyl hlo de d f l hl d

P p l p od ed l g am nt (ab t 20 000 000 000 lb/ye) lm t ent ely fr m pe t l m k g p m ly f g l e d by f th b lk ted by p lym z t lkyl t t h gl-oct g sol c mp e t Of th lm t 4,000 000 000 lb f p pyl e c med ll f h m l ly 6 me f m k g d p fi ll f h m l w mat l Th p p l p t ch m l de ed f m p pyl h w Fg 5 d T bl 3 Of th p o- p l l h l ty f the l g t l me a d th l pp h g sc l th l l g t th l d t es

N w l ge-sc l d t es f p pyl n l d p lyp p l d h d g p d A r l p od ed a m ll l f es l y f m petr l m by d ect t b m d l yd t d t l p pyl d be ed n p t w th petr le m de d hyd a pe o id in s d te to synth t glyc l The llyl chl ride ut l zed in th r g n l ute l s employ d in m k i g ep chl hyd n for ep xy re i s (F gs 5 nd 6)

T bl 2 P troch mi al f m ethyl

B der es nd sources	Prod ced ×10⁶ lb	Uses
Eth l d Y d oc d ton (ew l ta) 48 Y hl roh d 5	1 0	F h l l col 66 Di d t th l gl col 9 E h ncl m es 8 N d ge ts 7 Acryl nl 5 O h 5
Ethyl lcoh l(d trial) From th l 8 B f rm ts 15	1600	Ald h des 45 Oth h m cal 5 Sol 4 O h 6
Pol h l R dl gr capa bou 1500 × 10⁶ lb	700	F'lm hee m ld g d tru on
S yre From h l od ben- (or reform)	1170	Poly yre 40 S yre e-butad bbe d l 48 M sc es 9 Oth 3
Ethyl hlorde† Eth l + HCl ~88 Chlorination of th e, ~1	600	T ra h llead ~80 M nor mou for h h l ons (h h l cell lose)
Eth l d hlorid B d ec hlor ion 90 B produc f h l ne hloroh d prod c- ion, 10	800	V l hlor d 0 Sca ge knock fl d 0 Oth 10
E h l d bromid	160	Sca ger knock fl d

La es figures l hl
† T o process h droge l lorid from hane hlori and ea for prod on of h l hlorid from h l

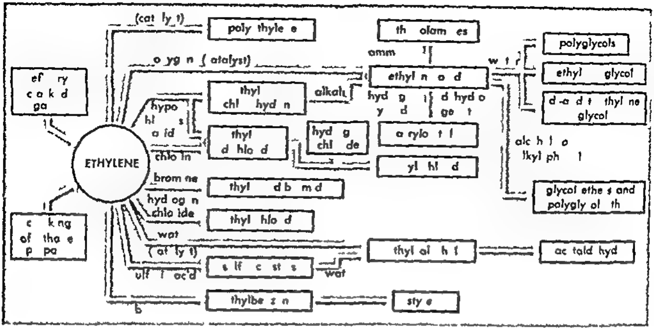


Fig. 4 Petrochemicals from ethylene

A striking example of the impact of petrochemicals on both natural products and other synthetics is the capture of more than three quarters of the soap market by synthetic detergents especially the sulfonate from propylene tetramer benzene alkylate with a corresponding drop in the production of glycerol as a by product of soap manufacture The gap in glycerol supplies has been filled by the introduction of petrochemical glycerol Also the assurance of a steady supply of glycerol from readily available propylene has been an important factor in the growth of alkyd resins

Table 3 Petrochemicals from propylene and the butylenes

B d n t es d sou ces	Prod ed lly X10⁶ lb	U es %
Isop pyl l h l F m p pyl ~100%	1 00	A t (by d hyd o- ge t l t) 46
Pr p e-b d t m ll		Oth h m l 13 Sol t d m sc 41
Dod (t t m)	340	D t ts dodecyl b
N (t m)	90	lf t yl t yl poly gl l th rs
C m	170	Ph l d
Allyl hl d	100	Gly l p hl o- hyd llyl l l l
Pr pyl d	80	M ly p yl gly l h h m l
P lyp pyl	Sm ll b w g	E pect d film l t m ll d tru
B t d F m b tyl es (f y ked ga) 60% From b d hoc 30% M sc hyd oca bo k g 10%	1540	Sty e-b t d bl 90 Acr l tnle-b d bb 3 Sty b tad pa t l t 3 Ad po t l d h m l yl ed m f yl 2 Otl
Sec d y b tyl l h l	250	M ly m thyl th l k
O l h l (C l d hyd) sooctyl lcoh l	40	D t ts pl rs
B tyl bbe (copolym f sob yl d so- p)	40	I t bes mech cal rubbe good
D sob tyl	110	M ly d t g ts pl t rs
T sob tyl	Sm ll	
P ly sob yl	40	Adhes es l ts lec l l b l dd t es
T t y b tyl l h l	30	Sol t

La est f g l bl

The butylenes (butenes) are in strong demand for the synthesis of high octane gasoline Chemical uses account for about 2 100 000 000 lb annually of which manufacture of butadiene overshadows all others Source of the butylenes is predominantly cracking conducted primarily for gasoline with ad hoc cracking of butane and miscellaneous hydrocarbons a minor but growing factor The principal derivatives of the normal butylenes and of isobutylene are shown in Fig 5 and Table 3

The oxo process (reaction of olefins with carbon monoxide and hydrogen) is used in a few plants It provides aldehydes from olefins of one less carbon number and from these by hydrogenation the corresponding primary alcohols Also in one case at least (using butyraldehyde from propylene) it provides by oxidation the corresponding acid (butyric for cellulose acetate butyrate) The principal alcohols obtained are branched chain octyl from the heptene copolymer of propylene and butylene (Fig 5) branched chain nonyl from diisobutylene and branched chain decyl and tridecyl from propylene trimer and tetramer respectively

Cyclic organic compounds The coal tar industry has been the traditional supplier of the cyclic compounds but since 1940 petroleum has become the chief source of many of them The principal petroleum derived cyclics are benzene toluene the three xylenes cyclohexane and their derivatives (Fig and Table 4) together with two refinery by products mixtures naphthenic acids and alkyl phenols Figure 6 shows only the more important of the cyclic derivatives thousands of benzene derivatives for

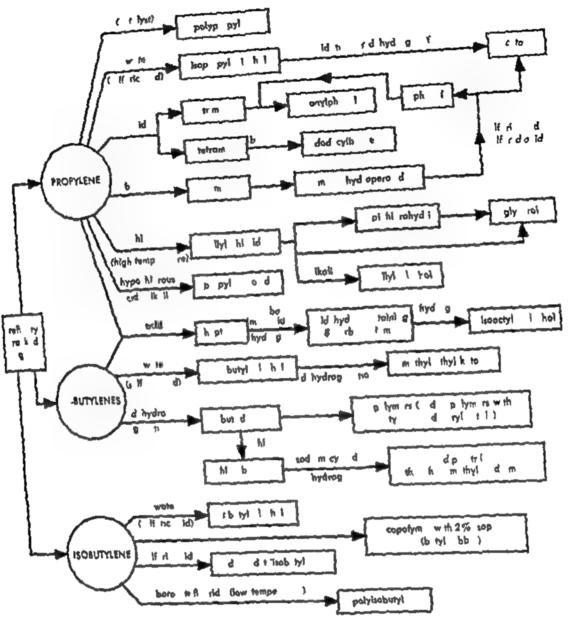
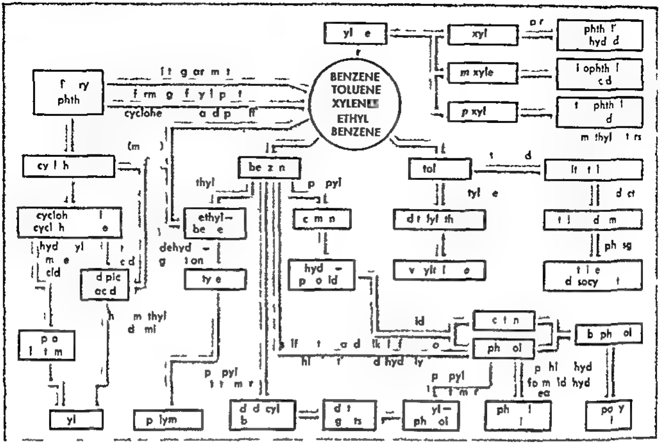


Fig 5 P r o h m l f m p pyl d the b tyl

x mple re k wn and hu dr d r an *ommer* al p od t n Th bow a e all known t be d r ed r s b t tal to age fr m p trol m H gh p lyme s (pl t es a d e r fibers a d ela tome) mpr e th g t bulk f the de a t with e d produ t ncl d ng nyle p ly ty e a d ty en bbe phe l si ep ty e poly tha es f m isocyan tes a d p-thal c polyeste Th *ar m t* hyd o bo s lso a f m h mp rtan t d ect es as h gh a ti k ock gasol e comp ts nd sol nt

Th u es f l hem l u e of pet oleum cy l e h d or rbon ha d pe ded t gly on th devel pm nt f pa t on techn ques ad q te t prod th eq red pu ty s e the so rce m t l at mpl x mi t e tar t g lso a variety f l w-bo l g p aff s and n phth nes Thes techniq es n l de c mb nat n of t ght f ac tion l d t ll t n eot p c d t ll t n e trac tive d tillat n s l ent n tract n l d adso p- n n ry tallizat on and chemic l c nver i n

Naphthen c ds are ca b yl ac d of b ti tut d cycl p tanes a d ycloh x nes they are p e ent crude o l Comme i l n phtl n c acids l e the m l cula we ght nge 180 350 Owing t the r o l olub l ty n phth tes of app op ate metal are used a p i t dr e s fungic des and lubr c t add t es N phthen c c d produ tio s abo t 16 000 000 lb a nually Alkyl *phenol* (cre- ylic ds) found n c ked petrol um the low r bo l g of th commer ial f ction onta xyle l a d m ller amou ts of cr sol etl ylph n ls tr methylphe l and m thyl thylphenol They a r che in o th and p ra is m r th n l t r phe l wh h are p odu ed at h gher crack ng temp ratures The b f uses n e flotat n f th rs d i fe tant il and ga l n dd ti e eng n and met l clea and phe l c res ns



F g 6 Cycl c petrochem col

Production from petroleum is about 36 000 000 lb annually

Table 4 Cyclic petrochemicals

B p od ts d sou es	P od ed lly ×10⁶ lb	U es %
B nz F m petrol m 35% From co l 65%	4 0	Sty 41 Pt t m (f t ly pet o- h m l) 4 Ph l lf t hl t 17 Sy tl t d t g ts ? M sc h m l d th se 31
T l F m pet l m 79% F m co l 21%	14 0 (f t) 50% f g sol ses)	M t t g sol 48 F plos es 8 T l d socy t yl t tl h m l 11 Sol f oat gs 11 Oth
Xyl F m t l m 90% F m l 10%	9 0 (0% f g sol)	Coat gs d sol ts 48 A t g sol 9 Isom pa (f phth l d) II O h l
E hylbe F m be p ed m t D ec f m l m m ll	1260	Sty ~100
Cy l h F m petrol m phth >65% F m b by hyd g t <35%	460	P ly m des† (yl) ~100

La est figu es l bl
† Th h m hyl ed m eq ed mes mostly from pe- t l m d d but d

Petrochemical sulfur Sulfur is obtained by the oxidation of hydrogen sulfide which occurs in ome natural gases and most refinery gases particu larly in the off gas from proce ses to reduce the sulfur content of petroleum liquids (for example hydrodesulfurization) Petrochemical sulfur production is about 1 440 000 000 lb annually (ele mental from refinery gases 590 000 000 elemen tal from natural gas 660 000 000 recovered as sulfuric acid from refine y gases 190 000 000 on a ulfur basis) Th s is about 8% of all ulfur pro duction n the United States

The total production of all petrochemicals hown as basic products or basic derivatives in the tables and text is about 24 000 000 000 lb The 40 000 000 000 lb mentioned earlier and sh wn in Fig 2 is a gross amount in which owing to the nature of the statistical information ome atoms are c unted more than once as they appear in uccessi e im portant products The total effort expended in pet rochemical manufacture is probably better repre sented by this gross amount *See* PETROLEUM PROC ESSING [H C \ T W E]

Biblio raphy W L Faith D B Keyes and R L Clark *Indust ial Chemicals* 2d ed 1957 B F Gold tein *The Pet oleum Chemicals Indus try* 2d ed 1958

Petrofabric analysis

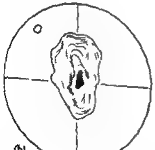
A stati tical analys s used to determine the ar ngement in space (orientation) of rock struc tu es b th on a large cale in r k mas es such as planar and l near structures in edimentary

rocks I a fl w ı neou ınt u o a d t eam depos t and l small s ale nternal on tit nts f rock such a pebbl ıncl ded fra me t nd m er l gr ı ori t d the by shape r by th ı ryst l l tt c t u tu e

A y m m t f a natu al bje t ı re ord d ın the po t o that the obje t ume n r sp n e to th m eme t. P efe ed or e tatio whı h ı a t t t cal pr l r n of num r bjects fo one po ıt ın t t t a r nd m a ra eme t n p c ı d te the d r t o and type of mo e m nt that a ed th p fe red r n ement *Ther fo e fab ıc a alys s may lead to a c gnıt o of the k mat c pr ce s by whı h o k a e f rm d r d f rmed*

Field measurements In the field ll v ıble *tru tu* of th expo ed ro k g e ı are m a r d ın a m ny outc ps a p s ble The res lt f these fi ld m a *reme t* a c n us f th t e d and ncl at of rıou pla ar nd l r t u t r The me ments are th n pl tted n a Schm dt t wh ch an equal area r l pr ject t l 10-cm ad The pl na tr t ı are plotted a gre t c cle L e t ııc t (a es f nt ect ng pl n or ax of f lds) a pl tted a po nt Th tatı t l s gn fi an e of

( )



(b)

F f b ıc d g m ( ) R d m g m ı ff ld ıp g l ıq ock (b) H gh d g f p f ed ne t f cry t ll g ph f quartz ın shea d g e O ı f 158 quartz pr cl lly ll lie w th th t d o ı h diag m th m m m on t ı n b g w thin the bl k e In th t (F om B S d G f g l d d Geol So M l g 1930)

the e mea u ements ıs empha ı ed by drawing cont u l n s (ısopleth) a o nd the ar a of equal de s ty of dı t ıbutio of po nt (ee ıllu tratı n) The pattern of preferred r ntation will th u b ome e ıde t a a ı s of maxım m concentrat n Patterns f rme l by ındı ıd al ets of mea u e ment f om e eral parts of one outcrop or f m n ut rop to another are c mpared to determine th n form ty of pattern th o ıgho t the area ın

tıgated Fab ıc d ag am that how uniformity of p tt rn re c mbı d ınt e t t tı al ag g egat Th r ult ng fab c dıag am ı then du ed ı ze s fficiently to ın ert ıt at the c r ct spot on the geolo ı m p of tl e whol are ın r d r t sh w th nif rm tructure fo thıt p rt of the are A map thus p epared h w th are s that have a ımilar type f tru tur ontra t w th other ı ea havı g a d fferent type

Sup rp ed struct res occu ı man reg ns f trongly deformed cks The re rep nted by d g ms *l owing d ffe nt tre d of fold ve* up p d n o e and the s m dıagram Such supe p ed t uct es kn wn as o erpr t c *then be further* tud d by a geomet ıc l rotat n f the d agram by wh ch the ın lın tıo ar fl t t ed ut t a h rızontal p ıt n a pro ess known as nroll g The tat on ıs c r ed ut ro nd the a ıs fo med t th mo t rece t deform n m m ts Unde lyı ı tr t re pr duced by e l e m m ts a then b ecog d

Study of hand specimens I ı on f ob c re o omple rock truct p e entatı e hand pe men ll ted f m *rep* entat ve po u e lter the geograph c dın te have beer ma k d n the pe ımen su h way that ach pecımen a be t p ın the labo at ry n exa tly the sam p t th t t had ın the fi ld By the u f uıtable n t me t t cture n th b meas r d ı th ee d m ns on whı h ın s me r cks g mo e s t f to y tructur l p tt rn than that bt n d from field d ta wh ch are c mm nly two-d m n ıonal

Study of thin sections Th tudy f th n e tı n de the m o pe g t ll furthe alu abl nform t o b t m *vem nt* reco l d n the r k fabr Arra g me t of th k makı g mı e ls by h pe nd also by ry t l l tt c t ı t r ı d t m ed by m ans f a p t oer ph c mı op q pped w th a nı e l t g ı D g ams prepa ed by th s t hn q g ve m h u u p ted ı f rmat n about the effects of m v m nt n k fab In cks too fine-gr ed to t ly u d the m cro ope x) an ly s c n g the de re l f rmat ı [E B K]

P bl g phy H W F b n *St u t al Pe t l gy f Def m d Rock* 2d ed 1949 E. B K pf and E. I g *St u tu l P t ol gy* Geol Soc Am M m 6 1938

Petrographic province

A r g n wh h th gneou ks f rmed d g l m t d p r d how rta mmun ty f h r cte (ch m l m al g al ı p tr l g

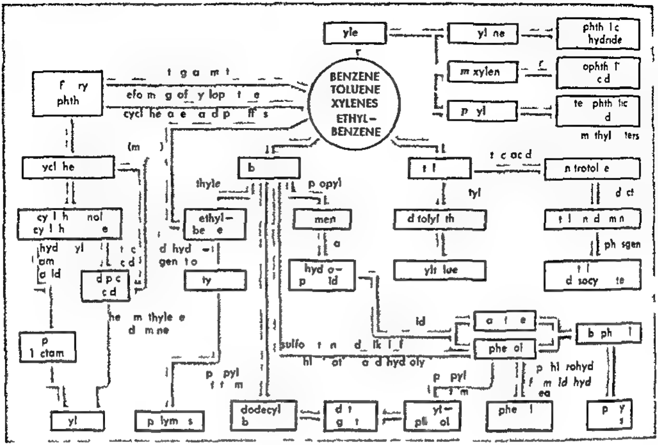


Fig 6 Cycl c pet ochem cals

Production from petroleum is about 36 000 000 lb annually

Table 4 Cyclic petrochem cals

B p od ta d so	P od d lly ×10 lb	U %
B	1 0	S y 41
F m p t l m 35%		Ph l m
F m coal 65%		(d fi t ly pet o- b m l) 4
		Ph l lf
		t hl 1
		Sy tl t d g ts 7
		M sc h m l i th 31
T l	14 0	M d
F m p t l m 9%	(f th	sl 48
F m l 1%	50% f	E los 8
		T l d socy t
	g sol	yltol th
	)	h m l 11
		S l tf t gs 11
		Oth
Xyl	9 0	Coat gs l sol
F m p t l m 90%	(0% f	ts 48
F m l 10%		A t g l 9
	sol	I m p t
	)	(f ph h l d) 11
		Otl l
Ethylb	1 60	S y ~100
F m be p d m t		
D ect f m f m t m ll		
Cy l h	460	P ly m d t (yl) ~100
F m pet l m phth >65%		
F m be by hy l <3 %		

Latest fig l bl
† Th h m thyl ed m eq l comes mos ly f m pe t l m d p d b tad

Petrochemical sulfur Sulfur is obtained by the oxidation of hydrogen sulfide which occurs in ome natural gases and most refinery ga es particu larly in the off gas from proces s to reduce the sulfur content of petroleum liquids (for example hydrodesulfurization) Petrochemical sulfur production is about 1 440 000 000 lb annually (elemental from refinery gase 590 000 000 elemen tal from natural gas 660 000 000 reco ered as sulfuric acid from refine y ga e 190 000 000 on a sulfur basis) This is about 8% of all sulfur production in the United State

The total production of all petrochemicals hown as basic products or basic derivati es in the table and text is about 24 000 000 000 lb The 40 000 000 000 lb mentioned earlier and shown in Fig 2 is a gro s amount in which owing to the nature of the stati tical information some atoms are counted more than once as they appear in ucces ive im portant pr ducts The total eff rt expended in pet rochemical manufacture is probably better repre sented by this gross amount *See* PETROLEUM PROC ESSING [H G V T W E]

Bibliography W L. Faith D B Keyes and R L Clark *Industrial Chemicals* 2d ed 1957 R F Gold tein *The Petroleum Chemicals Industry* 2d ed 1958

Petrofabric analysis

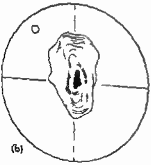
A statistical analysis u ed to determine the ar rangement in space (o entation) of rock truc ture b th on a large cale in rock ma e uch as planar nd lin r tructure in edimentary

rock l a flow , gneou t tru t n a d tr am d po ts, and also o a mall se l nternal n t t e ts f ock s ch pebbl incl ded f ag m nt and m e al grain i nted ther by hape by th ry tal latt tru tu e

A y m m t of n t r l object t ec rded in the po iti n th t the bject a umes in respon e t th m em nt. Preferred sentation, which i a tat u l p efe enc of um bjects f r one po it m contra t t a ra dom arrang me t in p ind tes the d ect n and t pe of mo e m t th t c sed the p efe red arrangement Th f fab c a ly m y lead t recogn ti n f th ki em t c proce es by wh ch rocks are f rm d o d l rmed

Field measurements In the fi ld all i ibl tru t es of the e po ed ock a g en area are m a ed i a ma y t r p s po ble Th e ult of these field mea u eme t i en s f th t d and in l nat o f v r plan r and li r t uct es These me rements re then pl tted n a Schm dt et wh ch i an equal a ea l lar p ject n t of 10-cm r d Th pl a tru t s e plotted as gre t cir les Lin t uc tur s (f i tersecti g pl ne axes f folds) pl tted po nt The stati t al s gn fica ce of

( )



(b)

f b d g m ( ) Ro d m g m f f ld p g g ock. (b) H gh d g f p f d f t f cry t ll g ph quartz h d g t Out of 158 q rtz p t lly ll t w h th t d eq f th d g m th m m m e t b g w th h bl k a th (F n 8 S d G f ge k d d G st Sp g V lag 1930)

thes mea urem nt i empha ized l fraw ng cont ur lin (se pl th l around the ar a of eq i l den ty f di tributio f poi t (se illu trat n) The patte n of prefe red orientat o will thu be com e id nt area of ma m im c centr t n Pattern f rmed b indi idual t f m a tre m nt f m everal p f ne ut r p r fr m ne outer p t an ther a e compared t det rm n the un f rm t f patt rn thr ugh ut the ar a n est gated F l ri d agram th t h w un f rm t f patte n are combined i t one t ti t cal ag g egat The res lt ng fabr di gram i then re du ed in ze u % a tl t i sert it at th rect pot on the geol gi m p f the wh le ar a in r der t h w th un f rm tru t r f r that pa t f the a e A map thu p ep red how the ar a th t h e a mil r type f tru t r n contr t w th th r a es ha ng a d fferent t pe

Superpo e l t u tures occu in m ny r gi f trongly d f rmed rock These are represented l d agram h wi g d ff re t tr n f f f l l a s pe posed in ne an l the sam d agram S h perposed tru t i es kn wn verpri t an then be furthe tud ed b a geometr al rotat n of th diagram l wh ch the l nati n a e fl t te ed o t t a h r zo tal po t n, a p oces kn wn a unroll g Th r t t n carried o it a ou d the ax f rmed l th m t ec nt d f rm ng m m t ll d l g t u t es prod ed l e tl r m m nt a then be ecogn zed

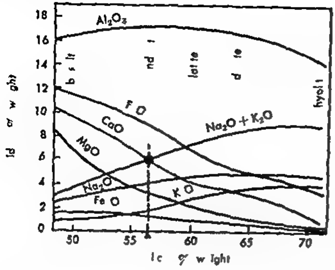
Study of hand specimens I g of ol se ir complex ock tru t res ep esentati e h n l pec m n a llected from rep esent i e e po u es after the geog aphic co d n tes ha e been m rked n th pecim t h way th t ea h pe imen can be et p in the labor t ry i tl th same po ti n th t t had n the field ll th use f n t ble i trume t t i ct n th n be m as u ed tl ee d m n i ns, whi h in som rocks g a m r s t fa to tru t ral pattern tha th t obt ned f om fi ld dat wh h are comm ly two-d m n onal

Study of thin sections Th tud f tl n sec t n d the m r sc pe g es till furth r lu bl inf rm t about m ement recorded in th ock f b i Arr ngeme t f the ock maki g m n ral b hape a d lso b cry t l l tt tr t i d t rmi ed by m an of a p t og aphi m p quipped with a u i ersal t g D a g m pr pa ed by th tech q e g m h n u pe ted nf rm t about th ffect of m e m nt ock fabr In rock too fi e-grai ed to t dy nder the m crosc pe x ray a l c n gr the des d f rm t n [E.B.K.]

B bl g phy H W F t n, *St u tu P t ology of Deform d R k* 2d d., 1949 E. B Kn pf a d E. I e son, *St u t al P t ol gy* Geol Soc Am. M m 6 193.

Petrographic province

A t wh ch the igneo s rock f rmed du in a l m ted p d how e tain mm ity f ha acte (h m cal m ne al g l p trol g



Igneous rock variatio d agram Repre ent ng the calc alkal series of volca c rock from San Fra c sco Mounta s A izona

ical) which distinguishes them from other rocks in the area Rocks of a petrographic province are consanguineous in that they are theoretically at least derived from a common parental magma A classic province is represented by the highly pota sic rocks around Rome and Naple Other provinces are characterized by either high or low content in other elements (such as sodium and titanium)

If the chemical analyses of rocks repre enting a genetically related series are plotted on a variation diagram many characteristics of the series may be brought out The accompanying figure show the percentages of oxides in each rock analysis as plotted against the silica content of that analysis

All points lie on or close to smooth curves which represent the variation in composition with silica content (or roughly with time becau e younger rocks tend to be more silicic) Noteworthy are the positi e slopes for potassium oxide (K_2O) and sodium oxide (Na_2O) the arched curve for aluminum oxide (Al_2O) and the negative slopes for magnesium oxide (MgO) calcium oxide (CaO) ferrous oxide (FeO) and ferric oxide (Fe O) The combined alkali ($Na_2O + K O$) curve is een to cross the CaO curve at 56 5% ilica This silica value is known as the lime alkali index for the rock series On the basis of lime-alkali indices the numerous rock series are arbitrarily divided into groups as follows alkalic < 51 alkali calcic $> 51 < 56$ calc alkalic $> 56 < 61$ and calcic > 61

Certain rock series appear related to c rtain types of geological en ironments In general the more alkalic types occur in regions subjected to tension and ertical mo ement (faulting and subsi dence) whereas more calcic se ies are found in compres ional r gions (fold mountain belts)

The olivine basalt–trachyte association Rocks belonging to thi a sociation are extremely wide spread The a ociation i well repre e ted in the central Pacific island (Hawaii Tahiti Samoa) the i land along the mid Atlantic ridge (Ascension Saint Helena) and islands of the Indian Oce (Kerguelen) Both mineralogically and pet graphically the association is relatively simp Primary olivine basalt magma has given rise to t following sequence largely through crystallizati and sinking of heavy minerals

Olivine basalt → basalt → andesite → trachyte

The last two types are not abundant Locally t series may be carried beyond trachyte to quar trachyte (Samoa) or soda rhyolite (A cension El ewhere it may pass through tephrite to phon lite The extrusion of phonolite may be due to strongly undersaturated (silica deficient) pare magma The quartz bearing end product may l due in ome areas to a saturated parent magm and in others (Ascension) to slight assimilation older granitic rocks

The characteristic development of oceanit ankaramite and limburgite may be explained b gravitational accumulation of olivine and pyroxen at lower levels in the volcanic re ervoir Den it stratification of this type would permit nearl simultaneous eruption of highly contrasting lava from neighboring vents

The olivine basalt trachyte as ociation m wel represented on the continents (Otago New Zea land O lo Norway East African rift zone Mid land Valley of Scotland) Here however the late members of the series (trachyte soda rhyolite and phonolite) are relatively more abundant and leu cite (rare in oceanic areas) may be locally impor tant

In general the a o iation occurs in re ion of faulting and marked ertical movement *See* MAGMA

Flood basalts These basalts al o known as plateau basalts form thick accumulation of nearly horizontal flows over vast areas (hundreds of thousands of square m les) Examples include the Columbia Snake Ri er basalts of Oregon and Wa hington the Deccan plateau lavas of we tern India and the Keweenawan la as of Lake Supe rior These flows were probably erupted through fissures f om great deep seated supplies of basaltic magma

Ro k of this as ociati n are ove whelmingly basalts but rare amounts of hyolite trachyte and ande ite occur Some geologi ts d tingui h two types of flood basalt olivine basalt and tholeiitic basalt The fo mer is sligl tly l wer in silica but higher in soda pota h and magnesia than is the latter Both types may occur in the same area They may be de ived from d fferent earth hell (at different le el) or the tholeiitic type may form from ol vine ba lt by cry tal f a ti nati n Other geologists con ider the two type me ely vari ation of a single primary ba alt magma *S* BA SALT

Intrusive ma ses (ills and d kes) of ba altic material (diaba e) form swarms o er tens of th u sands of square miles in many parts f the world Particularly notable are the nearly flat sh ets f diaba e in the ediments of the Kar ystem

South Af a d th flat Pal sade ill of New Je y The th ■ tab l r bod e of magma differ entiat d mewhat as they ooled a d ol me ac cum lated i a layer near the ill floo P ro ne i l ab ndant and mo e t o i h t ward the t p and plagi l e incre es i abundance a d soda conte t in the me d ect ■ The e relati ns d m o trate the c ntr l l crys tal fra t on t on and ttling in th pro e s f liffer nti t n S DI ABA ■

Basalt andesite rhyolite association Tl ande t rhy l te kind ed appear o onti ent and i typ c l of but n t e tri ted to reg ns of r ge y (f ld mounta n b lt) M t t k ng i the c rcum Pa ifi b lt f l an (many till a t e) ex te ely d el ped alo ■ the we tern marg n f N th and So th Am rica

Th ock con i t hiefly of and ite and rhyolite with maller am nts of ba alt da i latit and qu tz latite B th la a nd tuff ar epr nted The q ence f eruption f rock types i ex tremely mpli ated and v ri s with l cat on a well as w th tim Ba altic magma may ha e been th pare tal flu d n m st ar a Diff r ntiati n of thi ba c melt ha ope ated by fractio al cry tal liz tio but uper mpo ed p n ts ffects are th e of ■ im lat on of c u tal rocks and m xing of partly ry tall zed magmas (con nguineous) at arious tag s f d fferentiati n P s bly mu h hyol tic and a de iti magma w s g ner ted by loc l m lting of th c tal ocks

Basic ultrabasic association This associ ti n n l des ocks of b s c o ultraba c compo ti n d f und i l g h dlike a ce haped or o cal bod comm nly i) cted ■ sh llow d pth Ex mpl s include the D l th lopolith f M sot the St llw te omple of Monta the Sk g a d b dy f t Cree la d d the Bu h eld c mple f South Af i a.

Th k typ a d t b t d in fl t o me h t ba d l y ■ f m seque s th u nds f f t th k l ge al th k bec me h e t w d the bott m but n d t l th lay s f ntr t g types m y lte n te t g a t gl ba d d app r P d tite and p n te e m t ab nd nt ar the ba Upward the e g e way to o ite nd g bb o th me an rth ite Upp rm t ocks may b d o t to gra ti Oli v ne a d pyr e be me r h r n n a d pl g o l b m s mo sod f m bott m to t p n the e bod es

Su h d t b to s ugg t that th r gi ally j t d b alt c or b magma sol d fi d in ge l f m the floo pw d Cry tals may l e nit lly f rmed uppe eg o nd may h e ettl d t b ld ■ th fl Co e ti n cu r t n the melt m h h lp d t ed t b t d rt th e ys tal f d ff r nt s a d d n ty Th ■ d nt gr n t m t i l mm nly f u d th roc f m y r p t i ary g mo t a l t diffe t t f th r ki l ba alt c magm a p du t of m lat f l eou ks (d m t a d f] tes) by th magm ry t ll ed d ry m lt ■ n t d by th hot b i ti ion

Granodiorite granite association Th i exten s ly de eloped oar e-gra ned plutonic a em bl ge t r tr cted to continent an l may b ub d ided into tw c tegories. The fir t incl ide tl e maller m (tock ring dike et) mm nly widely cattered and f rmed ■ relati ely l all w depths The ma n ally tran gre the tr ture f rr ind ng rock but som a e highly e nc rdant a l m y ha eprea l r l med the ad jace t and erlying rock They are ■ ally ur r u de l by a metam rphic halo r z ne of re crystalli zat n which i ■ nerally m t con pi u u whe e the rock ha e n t been p evi u ly meta morph ed

Cran te an l grano l rite pred minate with mi nor am unt of d orit gabbro an l syenit present. M t bodies ha e probably f rmed by cry tall za tion f gr n te or granodi rite magma Wh r mi n r basaltic m lts l a been in ol ed cry tal frac t o at on and a m lati n of adjacent rock ma terial may ha e b ■ ope ati e S AUREOLE CO TACT

The sec nd category includes immen e deep se ted bod es (batholiths) surround d by meta morphic rocks and re tricted to orogenic zones The Sierra Nevada batholith of California and the Cos t Range batholith of Briti h Columbia are typ cal examples The predomina t rock type i gran te in those ma e of Precambrian age and granodi rit in th younger bodie Quartz d orite is somewhat le s abundant whereas diorite gabbro and syenite occur nly l cally B tholiths are g rally elongate parallel to the orogen ■ b lt but locally they are highly cro scutting The granitic rocks may be ma ve or foliated (showing parallel t eaking or layer ng of mi er ls) much lik the adjacent metam rphic rock into hich they ma appe to grad Many are char cteri ti ally a sociated with pegmat t s a d m gmat tes

Some of the e large bodi s m y f m fr m gra n t e magm de i d f y d wnfu kling and melt ng f the arth s iali (g an ti) layer Othe s may repre ent m re r le ree tituted (metam phosed) ed ments in ■ yncl n Still th bod te m y be pr ducts of ■ an t zat on Se GRANITI Z TION META ORPHIC ROCKS METAMORPHIS I MIGMATITE PEG IATITE

***Leucite basalt* potash trachybasalt** Th o ciati n i lud s a w d a ety f l c poo pota h ri h rocks f l a and near rface r gm Th a al o i nfin d t th c nti nents Bas (l w in S h gh in Ca F and Mg) nd ult ba la as with l t a d minant in m y r a O c r n ■ tr ct d but wid p d (R me-Napl It ly Uga da ea t Af ica W t K mberl y We tern Au t al a and L ucite H ll Wy m ng) Ro k type ncl de leucite ba lt leuc te ba an te t tash tr chyba alt a d m l l te ba alt The a ci t n appea s n reg on f fa lt g a d m rked rti l m ement S LEUCI E RO F

Spilite keratophyre association Thi a socia t n i cl de le n c flows and tuff w th m n t u e i i mat ly a c ated w th ed m nt

geosynclinal region. The rocks are soda-rich and potash-poor; they are chiefly basaltic (spilites) with some soda trachyte (keratophyre). Many appear altered (metamorphosed) and some are associated with rocks of the basalt-andesite-rhyolite suite. See SPILITE.

Ultrabasic rock. The predominantly peridotite and serpentine rock in abundant intrusive bodies is closely associated with the spilitic suite. Together the two rock associations constitute the so-called ophiolites, generally considered to represent the earliest magmatic phenomenon in orogenic regions. See PERIDOTITE.

Nepheline syenite association. Nepheline syenite and associated alkali-rich rocks are widespread but rare. They are continental rocks and commonly appear in areas of subsidence and faulting. See NEPHELINE SYENITE.

Anorthosite. This rock forms gigantic masses in Precambrian terranes and appears associated with hypersthene granite and norite. It is composed of andesine or labradorite and therefore differs from the calcium-rich anorthosite associated with gabbro in large stratiform sheets. See GABBRO.

[C A CA]

Bibliography: T. F. W. Barth, *Theoretical Petrology*, 1952; F. J. Turner and J. Verhoogen, *Igneous and Metamorphic Petrology*, 1951.

Petrography

A branch of petrology, the study of rocks, that emphasizes the description and systematic classification of rocks, especially by the study of thin sections under the petrographic microscope, by analysis of disaggregated samples, or by analysis of individual mineral components. See PETROLOGY.

The megascopic classification of rocks, based on characteristics observed in field exposures or hand specimens, suffices for some purposes, but refined description and classification require determination of the kinds, size, shape, and space interrelationships in the aggregate of original mineral components and the changes and alteration that have affected rocks or their separate components subsequent to their initial formation.

The petrographic investigation of a rock usually entails both an analysis of the rock after disaggregation into mineral or particle size fractions and examination of the rock in thin sections under the petrographic microscope.

Study of disaggregated samples. Techniques for study of disaggregated samples differ, depending upon whether the rock is composed of an accumulation of particles and fragments as in sandstone (clastic rock) or consists of interlocking mineral grains as in granite (crystalline rock).

Poorly to moderately indurated or hardened clastic rocks are disaggregated by crushing or pulverization, by dissolving cementing materials, or by using the disrupting effect of salts precipitating from saturated solutions with which the rock is impregnated. After disaggregation the size distribution of the clastic particles is ascertained by screen

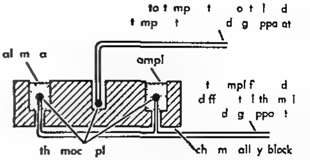


Fig. 1. Idealized diagram showing principal components of sample holder used for differential thermal analysis. (From E. E. Wahlstrom, Petrography and Mineralogy, Wiley, 1955)

analysis or by liquid or air elutriation, and the shapes, roundness, and surface characteristics of the particles are noted under a stereoscopic binocular microscope.

Hard clastic rocks and crystalline rocks, including igneous, metamorphic, and recrystallized or firmly cemented sedimentary rocks, are disaggregated by crushing into fragment sizes that will permit separation into mineral fractions. A variety of methods for separation of disaggregated rock into mineral fractions are available.

Separation of mineral fractions. Commonly used methods include hand sorting under the microscope, separation in heavy liquids, magnetic separation, and electrostatic separation.

Heavy liquid separation. Heavy liquids consisting of suspensions of ground metal in liquids are available with densities as high as 7.5 but are infrequently used because of the opacity. Widely used transparent liquids are bromoform, which has a density near 2.9, and acetylene tetrabromide with a density of 2.96. These are employed to separate heavy minerals from light minerals. Powdered rock, sometimes sized by screening and washed to remove the very fine fractions, are suspended in a heavy liquid in a funnel or evaporating dish and vigorously agitated to cause the light minerals to float and the heavy minerals to sink. After the heavy minerals have been collected and washed, successive crops of the light minerals may be obtained by careful progressive dilution of the heavy liquid with its appropriate solvent.

Magnetic separation. Electromagnetic separators provide mineral fractions differing in magnetic susceptibilities. Satisfactory electromagnetic separators are constructed to allow variation in field intensity at the point or area of separation, variation of the tilt of the poles of the magnet, and variation of the rate of feed. Best results are obtained with clean, free-flowing aggregates of uniformly sized grains. Electromagnetic separation is not satisfactory when minerals contain nonuniformly distributed impurities or ... product.

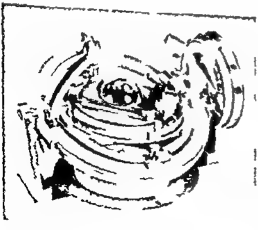
Electrostatic separation. Minerals of different electrical conductivities can be segregated by electrostatic separation. Mineral grains of approximately equal size placed on a grounded metal plate

ar d ffer nt ally attracted to a charged su face and eparatio of the d ffer nt min ral fr ctio is ac ompl hed by ry ng the int n ty of the ch arg or the sp g between the ch rg d u face a d the pl t ppo ti g th m n r l grai As in mag neti epar t on i e ularly n luded mpurities nd alt rat n p duct prevent lean eparation

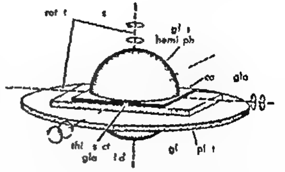
Study of mineral fractions Afte paration ach mi l compo ent i dentified by one f the e al t chniq es of d t rm nat e m neral gy (e MINERALOGY) Pr l minary i lent ficati n by phy i al p opert es nd by impl wet and dry test ng the pr dur s of y t matt ll wpipe analy m y p eced m re el bo ate t t Spec trogr ph a aly m c ochemi al te t or par t l r c mplet chem cal analy a e made to de tify gr tr ce elements. Part cularly u e f l n id t fic t on re x y d ffr ct patterns of po dered m n ral a rec rd d n f lm tr p or t d ch t on rec rdi g d ff actom t rs S CHE IICAL MICR COPY SPECTROCHEMICAL ANALYSIS X RAY FLUORESCENCE ANALYSIS

Minerals such as the feld p f ld path id carb nate and l y m n ral m y be t e ted hem lly so th t th y me d tinct e e l rs re ult ng fr m b o ption of dye f m p e ipi tat n f c lo ed hem al c mpound Mineral th t nde go rap d hem cal h ng s or crystallo gr ph n e on du i g he ti g m stu l ed suc f lly w th diffe nt l the mal ppa atu (F g 1) by determ n t on of hang f we ght d i g h t ng the wh n dec mp t on w th l s f a l tal sub ta takes plac D f f t l tl rm l aly mea ure th magn tud s nd tempe at re f e d thermal and xo th mal a t s i mi et l a they l t d in f rr e f m oom tempe t to t mp at res f 1000 C r m r S e EQUILIB II M PHA E T ERMOCHEMIST Y TR NSITIO PO NT

Rock n ti g wh le o pa t f l y m n l lay zed p rt le po pe l pr blem M e al f t o sep t d agg egates f l y m n l e t di d by ta n t is ay d f fr t p ttern d ff enti l th rmal anal



Fg 2 F o f st g (E L d f)



Fg 3 Th ect on m t d betw e glas hem ph e un rs l t ge (Adopt d f om E E W hl st m P t g ph M logy W l y 1955)

ba e exchange pr pert es infrared ab rpt on and the electr n mi r pe S e MICRO COPY ELEC TRON

Microscopic petrography For rock i wh h the m ral c mpon t are large en ugh t be id nti fied under the mic o c pe examinat n under a p tr g aphic m ro cope f thin secti n g ound to a th kness of 0 03 mm is stand rd procedure Th p tr g aphic microsc pe differs fr m an rdi n ry micro ope i th t it ha a r tating stage a d pola zi g filter r pri m whi h prod ce pt al phe me n t h tvai le in ordinary light Min erals r ident fied by th r opt cal and th er ph s al pr perties l y i g table and harts which rrelate phy i al p perties w th hem cal c m po ti

Min ral previ ly ep rated fr m di aggre g ted ck a e furth r anal zed under the m cro cope by plac ng fragments in l quid imm r ion med ums of know ef acti e indices a d d ter min ng th f act e ind x r indi es of the m n e al by mat h ng pro s A eful aid i optic l stud es th uni rsal tage (Fig 2) a m ltiaxis dev ce wh h is att ch d t the tag f th micro pe d perm ts ot t n f th secti n r m n eral f agm nt m unted i immer n medi m nto any de ed po iti n f the mea ureme t of pt al pr p ti s (Fig 3) Th ect s from wl h the c er gla has been r m d may be t hed and t ned t a d i the id ntific ti n of s me mpo t by th s me r g ts us d for t ini g er h d f agment

A p t cul ad tage of the thi e tion t h ju i that it ll w me s ement f the d me n f the mi eral mp ent a d reveals th nat of th conta ts a d the m nn of int g wth f the m ne l mpo e t Subtle d ff r e s n mp t n withi var ou porti n of gle ry t l twinn ng st n alter t n and other fe tures that m ght t be oted n n pt l t chn qu be ome very appa nt und r the m c o ope

M d The mode of a ro k pres e the m ne al c mp it n in we ght l me pe ntage The m l f l d o oth rw d agg gated rocks is obt in d by we gh ng the ep rated min ral

fractions The volume mode of rocks obtained from thin sections may be converted to a weight mode by calculations using assumed or measured specific gravities for each mineral component. Weight modes are used to calculate bulk chemical compositions of rocks after the composition of each mineral has been determined by optical or other means. The volume mode is determined by micrometric analysis in thin sections. With a mechanical stage several linear traverses are made across the thin section and the mode is calculated on the assumption that the volume of each mineral is proportional to the total of the linear intercepts for the mineral measured by the stage. A more rapid method employs a point counter, a mechanical stage which moves the thin section to a succession of equally spaced points in a linear traverse. The mineral at the intersection of the cross hairs of the microscope is noted at each point and the volume of each mineral in the rock is assumed to be proportional to the number of points counted for each mineral.

Space arrangement. The space arrangement of the mineral components is analyzed quantitatively by means of petrofabric technique. The angular relationships to the plane of the thin section and ultimately to the site of collection of the sample in the field of crystallographic directions, as determined by optical measurements or by observation of crystal shapes, are measured with a universal stage. Measured angles are used to plot points on an equal area projection, a special type of projection derived from the spherical projection. The density of points on the projection is indicated by contours so that the finished plot is a statistical indication of the preferred orientation in one respect or another of one or several mineral components. See PETROFABRIC ANALYSIS.

A specialized branch of microscopic petrography deals with opaque minerals, especially ore minerals, as studied under a reflecting microscope. The highly polished surface of a mineral or mineral aggregate is examined by reflected light which is directed onto the surface of the mineral by a vertical illuminator, a device inserted into the microscope between the object lens and the barrel of the microscope. Polarizing plates or prisms permit observations in plane polarized light. Minerals are identified by their isotropism or anisotropism, color, reflectivity, hardness, and response to a standard set of etch reagents. Small portions of minerals scratched from the polished surface are subjected to systematic microchemical analysis, x-ray analysis, or spectrographic analysis. See MICROSCOPE, REFLECTING.

Rocks containing both opaque and nonopaque minerals may be studied by making polished thin sections. Part of a section is left uncovered so that the opaque component can be studied in reflected light while the other components are examined by transmitted light by ordinary methods. [F.F.W.]

Bibliography: E. W. Heinrich, *Microscopic Petrography*, 1956; L. W. LeRoy, *Subsurface Geologic Methods*, 2d ed., 1950; E. E. Wahlstrom, *Petrographic Mineralogy*, 1955; H. Williams, F. J. Turner, and C. M. Gilbert, *Petrography*, 1954.

Petrolatum

A smooth semisolid blend of mineral oil with waxes crystallized from the residual type of petroleum lubricating oil. The wax molecules contain from 30 to 70 carbon atoms and are straight chains with a few branches or naphthene rings. They are microneedles and hold a large amount of oil in a gel. Petrolatums are useful because they cling, lubricate, and resist both moisture and oxidation. They serve as lubricants in baking and candymaking, as carriers in polishes, cosmetics, and ointments, as rust preventives, as waterproofing agents for paper, and in other uses calling for an inert greaselike material (see PETROLEUM PRODUCTS). [J.K.R.]

Petroleum

A naturally occurring oily, flammable liquid composed principally of hydrocarbons and occasionally found in springs or pools but usually obtained from beneath the earth's surface by drilling wells. Formerly called rock oil, unrefined petroleum is now usually termed crude oil.

Petroleum is separated by distillation into fractions designated as (1) straight-run gasoline, boiling up to about 200 C; (2) middle distillate, boiling at about 185–345 C, from which are obtained kerosine, heating oil, and diesel, jet, rocket, and gas turbine fuel; (3) wide-cut gas oil, which boils at about 345–540 C and from which are obtained waxes, lubricating oils, and feed stock for catalytic cracking to gasoline; and (4) residual oil, which may be asphaltic.

The physical properties and chemical composition of petroleum vary markedly depending on its source. As it comes from the earth, it ranges from an occasional nearly colorless liquid consisting chiefly of gasoline to a heavy black tarry material high in asphalt content. Although most crudes are black, many are amber, red, or brown by transmitted light and show a greenish fluorescence by reflected light. Their specific gravity is usually in the range between about 0.82 and 0.95.

Hydrocarbons constitute 50–98% of petroleum, and the remainder is composed chiefly of organic compounds containing oxygen, nitrogen, or sulfur and trace amounts of organometallic compounds. Pennsylvania crude oils contain 97–98% hydrocarbons; some California oils contain only 50%.

Hydrocarbon types. The hydrocarbon types found in petroleum are paraffins (alkanes), cycloparaffins (naphthenes or cycloalkanes), and aromatics. Olefins (alkenes) and other unsaturated hydrocarbons are usually absent.

Paraffins. The paraffins range from methane (found together with ethane, propane, and the butanes in the natural gas which accompanies petroleum) to n-hexacontane ($C_{60}H$ a m r crystalline w x) and mp und of n higl r molecular weight B th str ight hain a '

br nched ha par ffins are pr ent The f rmer u ually p ed i te pa t cul rly in the h gher b l ng fra t s. C mmerci l pa affin wax rd narily on t chiefly of t a ght cha n paraffin of f om ab ut 2 30 a bon at ms i l ted from the w de ut gas-o l fract n S ALKA E

Cy l pa affi s Th cy l paraffin are chiefly thos h fi e or x a bon at ms in the ring Thes n l de not nly the monocyclic ompo nds (ycl pe ta cy l h xa alkylcyclopentanes a d lkyl l hex nes) but also polycy l c hyd o-c rbon s ch as the bicycloparaffins (t s deca hydr aphthalen and c s b cycl [3 3 0]oct ne) a well a tr and highe cycloparaffins. S e ALICY CLIC HYDROCARBON

A omat cs A mat c hyd ocarbo s ar i ually pre e t n m lle am nt than the paraffi and cycl pa affi Th mati ompo nd bo ling n the g sol e an e are chiefly alkylben ne (such *a tol the xyle e p-cym ne)* Highe bo l g fra t on co t i polynucle r arom tic f both f d ri g (alkylnaphth l nes) and linked r ng (*b phenyl*) *types* The fused ri g polycycl cs ally p dom n t M no- and pol nucl ar arom tic ing fu ed t one o mo e cycloparaffin ring (as n *indan* a d 1 2,3 4-tet ahydronaphthalene) a e al o pre ent S e AROMATIC HYDROCARBON

Petroleum fractions The number of carbon a ms n hydrocarbons of a giv n b iling range de-pe ds on the hydr a bon type In g neral ga o-line will in lude hydr b n ha ng 4–12 carbon at m kero ne 10–14 middle d stillate 12 20 d w de-cut g o l 20–36

A tud f the g l n fracti ns fr m p e-nt t e p t le m f m even d ffe ent areas n the United St t s has perm tted ome intere ting l F e m i cla e of mpounds re pres t n the g line fr t o stra ght-ch n p affin br hed b pa ffi s lkylcycl pe tanes alkyl cl he an a d alkylb e es Al th h th r lat am nts f the l e are f om pet l m to petr le m th r l tiv am nts f the di id al mpou ds w th a g en cl ss f th am m gn t d l r th d ffe ent p tro-l m He th g s l fr t of d ff ent rude h te t ed by pec fying th lative m t l th fi ma n cla e

P t l m m y be cl fied a e da with th mp t Th P n yl t and M chi g l l r l rg ly pa affin a d ta l ti n a ph lt S me T x d Cal f rn a o l t h aphth wl th a u u n ll h h i om t m t e nt i mu h a ph lt A phalt d rk b wn o b k l d r m l d i g f a bon hyd xyg n ul f r nd m t m t g n ft m de p f thr c mp n nt (1) phalt e ha d f M n f bl p d r (l es n a m l d to s l d d s l d dh m t rial nd (3) il h h t t all m l t th l h at g il fr t o f m h h t de ed The ph lt a e al t mpl tel l t e a b d lfid e b t t hl de a d pyr d e but e nly p rtly l ble in low boiling paraff ns which d solve the oil and res n and prec pitate tl e a pl altenes See A PHALT AND A PHALTITE

Components other than hydrocarbons The to-tal oxyg n ont nt of cr de oil i gen rally l w but may be a h gh a 2% The oxygen-c ntaining c mpo nds c n t p incipally of phen l and car boxylic acid The phe l c mpri cres l and higher boiling alkylphenol The acid include traight-cha n and bra hed hain aci l s ch a hexanoic acid and 3-m thylp ntan ic acid and cy clopentane and cyclohe ane derivat uch a cycl p nt neacetic acid and ycl hexanecarbox yl c a id Th re s al me indicati n f the pre e ce l a id taining ar matic rings (mono-and d nuclear) Hence the name naphthenic acid wh ch ha been appl ed *to th carboxylic ac d* de-rived fr m petr leum i a mi mer petroleum acids i a pr ferable term

The n tr gen n tent f crude o l rang s fr m les than 0 05 to about 0 8% Up to about ne-half in the form of ba ic *pyr din* and *qu n line* com pound th latter predominating The nonba ic nitr gen comp unds or comple es include pyr roles indoles and carbazoles

The s lfur content varies o er a wide range from traces to more than 5% Pennsyl ania and mide nt nent crudes u ally c ntain le than 0 25% by weight of sulfur whereas some Califor n a and Texas st ck contai n er 2% Part of the sulfur may be in the f rm of elemental sulfur a d hydr gen sulfid Mo t is pres nt as *mercaptans* (thi ls) aliphat c sulfides and c cli lfide The merc ptans and sulfides ex t as both straight ha n omp unds uch p opyl *mercaptan* and *methyl* ethyl sulfide a d branched chain c m pound such as *te* butyl m rcaptan and methyl isop opyl ulfid The cy lic sulfides con t *of fi e- and* membered ring compounds such as *thia yclop* ntanes d thia ycl he ane

A numb r of m tal ha been dent fi d in the h (ab ut 0 01 to about 0 05% l y w ght) ob-ta n *d by* l urn g rude p tr leum The in lude od um m g es um calcium tr nti m copper il r g ld alum m tin lead nad um chro-m m m ga e ton cob lt *nickel* pl t num a d u a u Bo n s l n a d ph ph ru ha e al be dete ted It i quite bable that the s d m nd tronti m are pres nt hiefly in the f m of aq eo l ti ns of alt that a finely d p d n the il Mo t f the th met l are pr nt o l l ble h g n m tall c om p nds For e *mple nickel* a d nad um wh ch a e th mo t bu dant f the e occu g in 5–40 p a t p r m ll on in *many* ud o l f the United St tes p *obably* pr nt a po phyrin c m pl e S PETROCHE IICAL PETROLEU I (ORIGIN) PETROLEUM ENGI EERING PETROLEUM GEOLOGY PETR LEUM PROCESSING PETROLEUM PRODUCTS PROSPECTING PETROLEUM [L S]

Bibl g phy B T B ks et al (ed) *The Ch m i y f P t ol um H d o a bons* ol I 1954 A E Dun t t l (l) *Th S i e of*

Petroleum vol 2 1938 vol 5 pt 1 1950 H L Lochte and E R Littmann *The Petroleum Acids and Bases* 1955 F D Rossini B J Mair and A J Streiff *Hydrocarbons from Petroleum* 1953

Petroleum (origin)

Petroleum a complex mixture of hydrocarbons contains small amounts of oxygen nitrogen and sulfur compounds and traces of metal salts Accumulation of petroleum is believed to involve three steps generation of oil primary migration (the movement of oil from source to reservoir rock) and secondary migration (the redistribution of oil within the reservoir rock to form a pool) On the basis of the best available data these steps can be described as follows

Generation of oil Oil is generated in sedimentary basins These basins are shallow continental depressions hundreds of square miles in area that have intermittently been covered with sea water and are now filled with sediments The sediments are of three types (1) rock particles varying from sand to clay muds which were eroded from hills and mountains and carried to the basins by streams (2) biochemical and chemical precipitates such as limestone gypsum anhydrite and chert and (3) organic matter from the plants and animals that lived in the sea or were carried in by rivers Some of these types of sediments are being laid down today in basins such as the Persian Gulf and the Caspian Sea

The third type of sediment the organic matter is considered the source of petroleum Evidence for this is the fact that petroleum contains traces of several substances that could have come only from living things Examples of these are porphyrins related to hemin and chlorophyll which are components of modern organisms optically active compounds (compounds that will rotate the plane of a ray of polarized light) and structures related to cholesterol

It is believed that oil is generated from organic matter in one or both of two ways It may come directly from the hydrocarbons that marine organisms form as part of their living cells or it may come from the conversion of dead organic matter to hydrocarbon

Evidence of the first process is that some of the complex hydrocarbons in petroleum are comparable to those found in modern plankton kelp other algae coral and higher organisms such as oysters and bluefish When such organisms die in the waters of a sedimentary basin their remains drop into the material accumulating in the basin Their hydrocarbon content is low (0 005–0 1% by weight) and most of this is destroyed by bacterial oxidation However the total amount of hydrocarbon produced in this manner is so great (probably more than 1 000 000 barrels a year) that less than 1% of it would have to be preserved and accumulated to account for a possible 1 5 × 10 bbl of recoverable oil existing today in the land and continental shelf sediments

The second process by which oil may be formed involves the synthesis of hydrocarbons from the decay and alteration of buried organic matter It is believed that bacteria convert the organic matter into more petroleum like substances by removing oxygen sulfur and nitrogen in the form of water hydrogen sulfide and ammonia respectively The earth s crust contains such a vast amount of organic matter that if only traces of it were converted in this manner it could form all the world s oil

The synthesis process probably occurs over relatively short periods of time there are many oil accumulations that appear to have formed from rocks less than 3 000 000 years old In fact since hydrocarbon content does not increase with depth in the rocks of sedimentary basins synthesis may be essentially completed in the first few hundred feet of burial The temperatures under which the process takes place are probably low because the temperatures of petroleum source and reservoir rocks rarely exceed 100 C

A particular environment is required to preserve the biogenetically produced hydrocarbons and to make conversion of organic matter possible The source beds of petroleum are fine grained clay or carbonate muds deposited in basins under reducing conditions Coarse sediments such as clean sandstones reefs and oolites are usually not source rocks of petroleum because they are deposited in shallow water areas where water movement winnows out the organic matter and the oxygen containing environment tends to destroy hydrocarbons

Present day basins provide conditions that may be representative of those under which oil can be formed and that can be studied For example recent sediments in the Gulf of Mexico contain up to 0 05% of young (less than 15 000 year old) hydrocarbons that are of the same general types found in petroleum such as paraffins and naphthenes However certain differences in the structure and distribution of these types suggest that some of them are an intermediate stage between hydrocarbons from organisms and petroleum

Primary migration Primary migration of petroleum from source to reservoir the second step in accumulation is caused by the movement of water which carries oil in concentrations of less than 100 parts per million out of compacting sediments

When the source muds are deposited they contain 70–80% water The remainder is solids mostly clay minerals or carbonate particles As they build up to great thicknesses in a sedimentary basin water is squeezed out by the weight of the overlying sediments After compaction the source muds contain only about 25% water at a depth of 2000 ft and 10% at 6000 ft

The water and oil move in the direction of least resistance (lowest hydrostatic pressure) at a rate of about 1–3 in per year Early in compaction the direction of fluid movement is straight up As compaction progresses there is lateral as well as vertical movement of the fluid The lateral movement results primarily from the tendency of the flat

cla m ral y rt l t l e h r ntally as they are mpr ed Tl redu e the v rtical p rmeal l t f th mp ct g mud I add t on the lo g c n t o d n the dge of ba ns or ent flu d m n nt l te ally a bt rial prog e e

Th mechan n by wl h tl e water car es the l i u erta n It m v tra el m a y of three w y — ol tion a a oll dal di per m a d y l ts f l T an p rt t n m lut n is mpr ba bl b ca tl solubil ty of mo t p troleum l yd o-cbo n wat i o l w t a en nt f r know l cum l t o The dr pl t l yp th i im p b ble beca e th il wo ild ha n d ffc lty m m a th gh the fin p re ope i g m tl e l le Th il p bably trav ls s a ll idal di per n f o l at r t b l ed by tu al di per ng t Wh n thi d p e he tl e r rv r t l ty l w r d d th s han e m e ti n m t m au e gul t f the ll id l l ydro a b to f rm d r t ol pa t le

If th p ock mpl t ly en l ed w th mp ti g d the l part cle w ll l held m by the y ll v pr n the m d nd th w t r w ll pa th gh If th r p a enu f ap th t hyp es the m id hydr ulic cur t t d l tl m g wate will weep the l d pl t t f th es rv As mpacti n s a d o t l th wate i pell d l m th mud the ll d l p t t ght hales d be at Th l m th l f th m lat d il p t l

Secondary migration I nda y migr t n th l t t ge th g f an l c um l t th l d pl t r m ved b ut wit n th e r t f rr th p l Seco d ry m g t on l d m i t a d t p dur ng whi h n tal m em nt f th a th hift th ro n a f th po l w th tl r erv r r ck

Th p ti n f th e mul t g p l affect d by l met fl t g fa t Bu y l t e k the h gh t p rm abl part of th e rv i p ll y f e dire t th il t th t g a n d p t n fi t and nt l fi a n d p ti n th r rv fill d A v p rm abl ty ba n th e r o r n n f the l i t m what a d m dit b t n O l m l t a h t k ft n ti be p t f th ng l d p es h b n pl gg d by mi e al ntr d d f m w t l t afte th r ck f rm d l l g d bod t f m d by th n l of d hal m h ld th l r l el Wh t l m me t f th ea th c l p ol ar om tim h fted aw y fr m the pl wh h th v ll m l ted F lt m t me t th gh rso dest y ng p rt f the pool h ft g them t d ff t d pth Uphft a d b g th p l ar the f wh the l ght hyd rb po t F tu ng of th ck llow l t mg t rt ll to mu h h ll w r d pth Wh ev r d ff e tal p s t r a d p m bl p n ng h as f t es p id path b t l um w ll m

The c mp ti n and har cter f th l ulti mat l y f rmed i e ntr lled l y all t ha of u or gin and migrati n Tl org n c tructi r fr m wh h the il originated tl e l ti ity f tl e mi grati n pha e t picking up ly part of th hyd o-carl n fr m tl re rock and tl alterati n of the l with n the r rv ir l y il r face water and gr und m e n nt are l l e ed t play an m p tant part m determining the mpo iti n f petrolei m S e PETROLE t PETROLEUM GEOLOGY SEDI IENTATION (GEOLOGY) [J r HI]

Bibli g aphy G D H l n S m *F i d m tals of P t ol um Ge logy* 19 l A I Lev r n *Geol ogy of Pet ol um* 1) l F M Van Tuyl H H Parker and W W Ske ter The migrati n and ac um l ti n f p t l um a l natural ga Q a t Colo School M i 40 l 11? 1)15 l (Week (d) *H bit t of Oil* 19 8

Petroleum engineering

The appl cati n of alm t all typ of e gi e ring t tl e d ll ng f and pr d ti n f l ga and l qu fial l *hydrocarl n* It l ies n t m l refin i g of l quid hydroc rbon n l ng d ta trans-p rtati n wl h ar r pe ti ely red l y refin ery e g neeri g and pipel e a d mari e eng n r g S PETROLE I REO rs t G IPELINE

Petroleum e gine ing appli es t il mechan al nd h m al g neeri g proce es a well therm dynami and l ydrod nam to the pr l l m of p oduci g l ydr l Exampl f i pr l l m pet l im ng eering are di cu ed h t tl arioi pr llem a too n imer and mpl x to p rm t mpl te n d rat

Th petrole m ngm r i e il engi ring in urveying pla n ng u fa e t an p tati n s tem and n th de gn an l lect n f l f eld eq ipme t M ha i al engi e r ng s i ol ed n th op r ti and t lizati n of ga and d el e gi e el tr al m t r and r el team en nes and thei rel ted eq pment Therm dynamic i th b i f nde ta d ng u derg nd m i ment f hydro rb the ph lat and th r e e f l quefi bl hyd oca bon from ga es Hydr dy am s i vol d n flu d fl w t tl pay f rm t rr lly m t l g a g and fa e g th r g and d tr b tio y tem Cl r al e g ne r g nta led m th p p r d f th d ll ng mud th pr te ti n f quipm t ag t rr nd the t at ng of both l and g ft p d t Se OIL AND GAS FIELD DEVEL O MENT

Drilling In d ll a w ld t well a p t l um g m st the lo at n t mak ta n that th w ll i drilled at th d r d d ta e from l a l es and wells on th perty d by th e g le H mu t pr de a e ads f l a d w t pple t tle f u dation f the d ll ng q pm t and m d p t fo torag l dr ll ng m d f r tth g f e tt g fr m the m d and fo i t ng tl e m d as may be n e ry

M e tha 80% f m de n w lls a d all d p w ll a e d ll d by th r y p A d ll g

bit is turned at the bottom of the hole mud pumped from the surface through the drill pipe cleans and cools the bit flushes to the surface the rock cuttings that have been torn loose by the bit and provides pressure to prevent collapse of the sides of the holes before casing is inserted The mud must be heavy enough to prevent flow of fluids into the hole during the drilling operation In soft or unconsolidated formations care must be taken to prevent the hydrostatic pressure of the mud from forcing the mud into the surrounding formation Excessive mud weight may result in loss of mud to such an extent that gas oil or water may break into the hole and erupting at the surface destroy the drilling equipment and tear out a crater at the surface with resulting loss of hydrocarbons and damage to nearby properties *See* BORING AND DRILLING MINERAL OIL AND GAS WELLS

In some areas mud is formed by simply pumping water down the drill pipe and mixing this water with the soft clays which have been cut loose by the bit But drilling mud is often an expensive and carefully engineered fluid produced by additions to the natural drilling mud The cost of drilling mud varies from zero under most favorable conditions to costs exceeding $10 per barrel of fluid It is not uncommon for mud costs to exceed 20% of the total cost of drilling under difficult conditions Careful chemical and physical testing may be required at short intervals to make certain that the mud has the desired characteristics and to plan for varying those characteristics as the bit penetrates different formations in depth *See* GEOPHYSICAL EXPLORATION PROSPECTING WELL LOGGING (MINERAL)

The well having been drilled to a specified depth or to the point where commercial deposits of hydrocarbons are expected tested or proved the hole is protected by running (inserting) a string of casing The engineer must select casing of proper strength diameter and wall thickness so that the string can be lowered into the well without parting under the strain of its own weight It must also have adequate collapsing strength so that it will not be crushed by outside pressures when fluid is removed from the casing Commonly important savings result from varying the strength and wall thickness in different parts of a casing or tubing string Maximum tensile strength is required at the top of the string to sustain most or all of the entire weight Maximum collapse strength is required at the bottom of the string where external pressures are at a maximum

The casing is normally protected by pumping neat cement through it and permitting this cement to rise along the outside of the casing toward the ground surface Cement quality must be chosen with full consideration of underground temperatures and fluids to allow ample time for pumping the cement to the desired position before the cement sets If the cement does not rise to the desired point outside the casing the casing must be perforated at one or more points and additional cement pumped through the perforations to form a cement sheath around the casing When cementing casing a plug is placed in the casing at the top of the fluid cement Mud pumped above the plug forces the plug to a point near the bottom of the hole so that little cement is left in the casing when the pumping operation ceases

Frequently and normally in deep wells more than one string of casing is required to complete a well For example the normal hydrostatic pressure of fluids existing in the penetrated formations is 0 465 psi per foot of depth In some areas notably the Gulf Coast of Texas and Louisiana certain formations contain fluids under pressures approximating the weight of the overburden so that the hydrostatic pressures in these abnormal zones may be 1 psi per foot of depth Counterbalancing such a pressure requires mud weighing 18 lb/gal If such heavy mud is used in formations of normal hydrostatic pressure the mud may be forced into the surrounding formations and fail to return to the surface the well may then be in danger because cuttings which should have been removed from the well by the circulating mud may settle and allow pipe to stick Accordingly the well is drilled with 10–12 lb mud to the top of the formation where abnormal pressure is anticipated and casing will be landed and cemented at that point The mud weight is then greatly increased for the zone of abnormal pressure The petroleum engineer must design his mud and his casing strings to protect against such varying condition

Surveys are run during drilling to secure data on the straightness of the hole and the temperature encountered Unsurveyed wells have wandered (deviated) as far as 2000 ft distant from a vertical line through the well location Electrical neutron and gamma ray surveys determine the porosity of the formations penetrated and the character of the fluid in any porous rocks Most of these surveys are made by specialists but the capable petroleum engineer is prepared to interpret the surveys and to adapt his operations to the conditions shown by such surveys

Gas oil separation problems Hydrocarbons occur underground under pressure and temperature normally far in excess of surface conditions The engineer must plan to separate the oil from the gas at the surface direct the oil after measurement to pipeline and where necessary transport the gas to gasoline plants where liquefiable hydrocarbons are removed from the gas the gas is then dehydrated sometime treated to remove sulfur compound and residue gas is made available for sale to gas pipeline or for use in repressuring or recycling a producing formation *See* OIL AND GAS FIELD EXPLOITATION PETROLEUM PETROLEUM GEOLOGY

Under high pressure and temperature all the gas may be dissolved in oil so that the formation contains only a single liquid hydrocarbon phase Conversely if the volume of heavy hydrocarbon is relatively small all of the oil may be dissolved in the gas so that the single hydrocarbon phase underground is a gaseous phase If pressures are reduced from hydrocarbon liquid condense

gas f m l q d in the pay f rmat n and are held b apillary att act on nd thus lo t If a gas p ol e nt ns m h l qu d n ga oluti o and if th s pool i prod ed an d n y ga pool the lo s of co de s t (l quefi ble hydr arbon) n th p y ma xc ed 50% f the liq efi ble n te t a e u eco mi l t the p odu er Fur ther th e l q d by blo k ng m nute connect ons bet e n the po e pa m y r o ly imped the fl w of gas nto th well a d thus extend th pro du t l f f the field a m ch a 100% Con e q ently ult m te g s re o ery may be r d i ed a m h 25% Th n f rtu te re ult may b pe ev ted by grad ally withdr wing the g s, tr p p g it f l quef bl hyd a bo and re njecting the dry nde high pre ure i t th pay Th op at known cycl e p n se l e e the retur ed g s mu t b c mp e d t a hi h r p e ur th n th e t ng pr u e in the pay H gh p e su gathe compre r g nd d t b t n fa l t es ar equ ed E tr m ly ac u ate g e g mu t b appl ed t d t rm n d a e h the the t f e y l ng w ll be g at r l s tha th lu f th e vered l t d nd l o wh the th be fit f ed t n i pe at ng tim h the p l ope ted w tl out y l ng e eed th net p fit e ult g f m pp n th l qu d fr m the ga bef e the a ail abl g ma k ted S PETROLEUM RESERVOIR ENGI EERING PETROLEUM SECO DARY RECO ERY

Recovery problems Oil pool pr duce under f m l n m g sp n gas-cap dri e wate dr d g a ity d a n Comm ly two r m mech m op t i gl pool The pet l um nee m t b le t t take f ll d nt ge f any p ibl wate dr a sp d h ch w ll p rm t r ng a l rg p r tage f l n th p y format n tha a b bta d u de g p n d e

F qu tly by ex ng n the l at n f w ll a d at f pr d t n f m ndi idual ll i m p l m b double th t wh h w ld h b en u d by ga e p n n gra ity d g S met me ga w t o ien m y b nj t d t a p l to d pla a d f l r th p du g w ll l y ti n of x t u m te i l d a lt g n re e i l p o d ti n r f rr d to a o d ry ery

W t d s a e th m t ff e t f rm f nd y c ry nd may b e pected t produ e tw m ch l m y be d by g nje t Eff t to mp ec d ry e v by w te d l th se f m i als wh ch w ll e d th u f t n f o l n the pay a d d the fl t f p ll y ttr t n in h ld g l n the p Add ti pl e d i th w te ay i c e ts rf e t n i n t the p t wh t ll d pl l Oth r dd ti m y red e the f te n f the l d p w t ts d pl m t Add ti a e e p a d th i n t lway j tified P m e p m t el d th i ti n f l ght h d a b n u ha pr pa e d b t n had f th w t Th l ght l q d mb g w th th l d e t ty nd n

duce more complete flu l ng fr m the pay Natural ga carbon d ox de or a r are metime intro duced int th water drive to a i t in m ing il from the p y Th petrol im ngineer mu t de termine whether sec lary re ery perati n a e ju t fi d if o h mu t e l ct the meth d and the dd ti e if any wl i h will g e the larg t con m c return fr m the m ey inve t d in the condary r e ery work

Corrosion Thr gh ut the pro luct e life f a fi ld the gineer faces the pr ll m f co r n Carb n d oxid in ga l ydr gen lfid in ga and l and alt water all c r de ca ing t bing cker r d tank and other quipment These may be ombated u d r arying nd ti n l y e le t n of pecial teel c ntaining varying p r ce t ge of ni k l chr mi m and ther all y ng m t l Corr n combata t ch as an alkali or fo maldehyde are f eq ntly i d to ne trali hy dr gen ulfid and c rl n d x l Some ucc s ha been bta ned by co ting e ker rod and in tern lly ti g t l ng urface l nes a l eq p ment w th pla tic In ge eral pa t l s e n t be n e ful n prot cting eq pm t again t rro i e flu d

Oil-water separation The ngin r al applies chemic l enginee ng t tr at ng l t eparate wate f m il emi l n The t at ng may con t f merely h ating the il t f l tate the para t n of wate fr m il S met mes th well flu l i filte d th ough hay tr w r x el i r atu ated w th oil whi h r je t the w ter and p rm t el n l t fl w thr ugh th filte A wi l rang of chem ic l is d d p ding the h m i al c mp i t n of the o l t break d wn the m l ns In s me areas elect t ti epar ti n f il from wa ter chi ed l y p i g the fl d b tween in i lated ele t cally ha ged plat Combi t n of ll the pr ce es are su e ful some area Co ersely som l mu t l e wa hed with water t r mo e dium hlor de and ther alt from usp n n Aga n the su e f l e g neer mu t e lect the proc s b t u ted t th c nd ti n xi t ing n th field f m which p od ti n l t n d

Production forecasts The pet leum ginee mu t p edi t th prod ction of ga nd of o l both lum a d t me Th number of wells t be d ll d th t of p ducti n l th type f eq ipm t t b n d w ll ary depending the p ed ct n a t life f th field a d th lumes f l ga a d ate t be produced l d tions a mad m t r ughly b a vol metr cal lati n whi l att mpts t dete mine the l m of p r us r ck wh ch s t r t d w th o l th p ntag of p r s ty th ro k th per t ge of w t t t n the por pace the h nkag f the o l e lt ng fr m relea e of g a d th p t ge r o y f th a l bl o l N e ry t ns m d f th diffe n e betwe t mpe atu nd press t th f rmat on and nd r sta da d d t s Cor p nd g e t mat r mad f r ga pr du t When a p ol i fir t d s o d the nly r erv e t mat wh h can b m de is b s d n olum t c calc l t s wh h a e ril

inaccurate because the engineer does not have complete data on the various parameters. *See* PROSPECTING PETROLEUM.

After a pool has some producing history, the engineer may estimate the ultimate production on the basis of curves comparing production against the declining pressure or decreasing rate of production. In gas pools, the accurately determined volume of gas produced per pound of pressure decline usually provides a good estimate of future production. However, an unanticipated active water drive in the pool may cause an excessive estimate. A material balance equation gives the most accurate measure of available reserves, provided necessary data are available. Estimates of productive life depend upon estimates of ultimate production and the estimated rate of production, which rate normally decreases as pool pressures diminish. Production rate should never exceed the maximum efficient rate of production, MER, which is the highest rate of production which can be maintained without underground waste. MER is frequently decreased by conservation regulations, by limited marketing facilities, and by delays in effecting unitization or other arrangements necessary for secondary recovery operations.

Predictions of reserves and of producing life are fundamental to the proper management of the field, the financing of the production operations, and the program for exploration in search of other productive fields. [R.S.K.]

Bibliography: R. L. Huntington, *Natural Gas and Natural Gasoline*, 1950; M. Muskat, *Physical Principles of Oil Production*, 1949; S. J. Pirson, *Oil Reservoir Engineering*, 2d ed., 1958.

Petroleum geology

The application of geologic principles in the discovery and development of oil and gas pools. The geology of petroleum includes the origin, migration, and accumulation of petroleum; the structural and stratigraphic relations of oil and gas pools; the lithologic characteristics of formations and producing horizons; and the use of index or guide fossils in correlating horizons.

Geological aspects treated here include the occurrence of petroleum, the character of reservoir rocks, typical reservoir traps, and the general nature of reservoir fluids. For further treatment of the physical and chemical properties of petroleum, the origin and migration of petroleum, reservoir and production mechanisms, and geological and geophysical methods of exploration *see* PETROLEUM; PETROLEUM (ORIGIN); PETROLEUM ENGINEERING; PROSPECTING PETROLEUM; *see also* MICROPALEONTOLOGY; PALYNOLOGY.

OCCURRENCE OF PETROLEUM

Petroleum deposits may be classified as surface occurrences and subsurface occurrences.

Surface occurrences. These occurrences may be thought of as currently active or live occurrences, such as seepages, springs, exudates, and mud volcanoes and mud flows. Others may be termed fossil or "dead" occurrences, such as bitumen-impregnated sediments in exposed deposits and dike and vein fillings of solid bitumens. Another surface occurrence of petroleum is oil shale, a borderline material between the petroleum hydrocarbons and the coal family.

Seepages, springs, and exudates. Petroleum that exudes in any of these forms may reach the surface along fractures, joints, fault planes, unconformities, or bedding planes, or through the connected porous openings of the rocks. Most seepages (or springs) are formed by the slow escape of petroleum from fairly large accumulations that have been brought close to the surface and into the zone of fracturing by erosion, or that have been tapped by faults and fractures. Almost without exception seeps are at topographically low spots where water has also accumulated. Oil, which is lighter, rises to the surface of the water, covering it with an iridescent film. Many pools and producing regions have been discovered by drilling near seepages.

Exudates of asphaltic oils issuing at the surface are likely to be changed to asphalt, partly by the escape of volatile fractions but mainly by chemical changes such as combination with oxygen or sulfur. The asphalt is black in color and varies in consistency from a sticky liquid to a substance hard enough to walk on. Outcrops of asphaltic oils are sometimes marked by small pools (less than 100 ft across) which have collected on the surface of the ground. Many of these pools contain the bones of animals that have been caught in the sticky material. Asphalt found at the surface has nearly always seeped up from the bedrock in the vicinity, but there are a few instances where asphalt has been carried by water. Asphalt of natural origin has been found floating in the Gulf of Mexico from Padre Island to Matagorda Peninsula, Texas.

Mud volcanoes and mud flows. These are high-pressure gas seepages that carry with them water, mud, sand, fragments of rock, and occasionally oil. Mud volcanoes are usually confined to regions underlain by incompetent softer shales, boulder and slump zones, landslide deposits, salt and sand, and unconsolidated sediments. The surface of a mud volcano is often a conical mound or hill with an opening or crater at the top through which issue mud and water, which are usually salty. Only the type which emits gas with or without oil in addition to the mud and water should be considered a surface indication of oil or gas. Mud volcanoes occur chiefly in areas of Cenozoic rocks that have been strongly deformed. *See* MUD VOLCANO.

Solid and semisolid deposits. Tar, asphalt, wax, and hard brittle bitumen (any of the flammable viscid liquid or solid hydrocarbon mixtures soluble in carbon disulfide) are popularly regarded as solid, although strictly speaking some of them are highly viscous liquids. Outcrops of solid petroleum are found in the form of disseminated deposits and as vein or dikelike deposits filling cracks and fissures.

D em nated depo ts are sediments c ntaining petr l n the f rm of a pl alt I t m n p t h thi k h a y il d emin ted thr gh th p re f o k the as a matr x as the bond in m t r al Th y a e mm lv lled l t m nous sand bit m l me tone depend ng on the n ture f th h t ock Tw d ff ent type of d m t d oc urr nc s are found n p ated de p t d prim r m t r of ck a d b t men In p ted dr ed p dep ts are n t (in pla e) a d ere p bably n a p ol in liqu d nd g eo f rm Th y now c n i t f nl the m e r tant a d he v id e the l ghter f a ti ns ha n been l t An n p ated d p t m be th ght f s a fo il oil fi ld A er n g d ally r moved th ove bu den l g ng tl e rfac lo e to th p l the decre d pr u e pe m tted ge and l ght r o l fr cti ns t come o t f l t n and e pa d l a ng the h a r hy dr c b f cti ns behi d A tl p ol ap pr ched th u f w athering th p ng f r pi nt f a t ll wed th ga s t es ape more ead l Oxid n agent ded ol d f i g the h a i l th t rem ined b h nd

P mary m t a th e s which the edi m t w e mi d with th l a phalt r ta d r t gether d p t n th wh l d po it h ng later be n b d by c ed m nt a d th n ex p ed by er Th Athaba a l ands Al be t Can d th ught by ma y to be uch a d p t O th th t l eep d p fr m the i ly g nd th n o t J p n De m n o ganic l mest n a d w ed p ted d n Cr ta eou t m t eth w th C ta eo nd in l goon d b rr d l n al n th h Th l nd m k n de d t m y di m nat d d po t wh h th nd w d p ted o w th th il S O i sa o

D ke d fill g m y be eg rded as f ssil d d seep g s f m wh h the ga ou d l q d f a t r h e b en em ed l g o ly the l d r d s b h d In n p t d d po t the sep t f th l ghte n t t ts c d n pl e n th o k I th p m y d p s t the s pa t n f th g f m th l q d took pl b f th t mp n dep tio f th il and ph lt with th l g d m nt l th old n nd d k fill g the los i th g us and l q d f a t on p b bly o ur d wh le the pe t l m filln th open g

O l h l k wh h y ld bund nt o l n d t ll t ge er lly bout 5–10 gal m to th t lt bo d i e l s of hyd b ma t l ha ng som f t p p t s f p t l m d m l l O l hale c n t f l d hyd o bo n th n t f tat B t th d n t d mp e i t g ee s and l q d p t l m h d o rb u t l th y e h t d t t mp tu e of 350 C m Th ld l t l sh l hi h yi ld l wh n he t d we e o all d k g n b t s many d ffer nt m g h e be g n t th w d that t n t good nt fi t nd g today S O L SHA E

A phalt i a dark colored pla tic to fairly hard ub tan e a ily fu ible and lu le in carbon d s lfde It c ur n nat re but it i al o l tained a the re due from the refining f c t m petro leums the it is kn wn a artifi i l a phalt A phalt melts between 150 and 200 F It may occur a e page urf e a c m lati n and impregna t ns A phalt m y also occ r i larg lakes One f the best examples f t ch a lak i the Ran h L B e dep it i Lo A geles

A phalt tes a e harder hi l ydr carbons which d ffer fr m a phalt in bei g trictly f an intru i e natu The are f und in m or d k c tting acr the ed ment A ph altite are f ible but melt at mewhat high temperat re and are h der and heavier th n the a phalt S A PHALT A D ASPHALTITE

Natur lly oc urri g m n ral wa es re ol l h dro arbon b l e ed t re ult fr m the drying-out f a pa affin ba e l O e example is z ker te a pla ti wa l k ga affin se m t ti l which an l e f und in Utah a d n ar B ry law P land S e HATCHETTITE OZOKERITE

Subsurface occurrence Und rgro nd oc ur re e of petrol um may l e cl f d pool field l p i

P l U d rg nd a umulat ns f petr l m haracte ed by a ingle and ep t te natu l res erv r (u uall a p r and t n lime t e) a d a i gle natural pres ur y t m ar c ll d p l Th pr duction of pet leum fr m part of a p l ffe t th reserv thr ugh it it tte t A pool i bo nd d by geol g barr r n all di ect u h a ck t ct e imperme ble t ta and wat in the f rmati n that the p ol effect ely parated from any other pool that may l p ent i the ame di tri t r n th me geol tr ict re

Fi ld An l fi ld may be a gle pool r it may co t of two or m re p l all r relat d t the ame geolog c l ct re Where m re than on pool i p ent the am fi ld the d ff re t p ls a e par ted f om ne an the The diff ent p ol m y occur at eve l h z i d fferent g ol g ep rated by impery f mat d th may p rt lly or mpletely o erlap on th h iz nt lly r they may n t o lap at all G l g f atu that a e l k ly t form fi ld a e alt plu ant l nally f lded m ilt ple and nd omplex mb at f fa lt f ld g and t t g aph mb nat

P i A p n i a r g on n wh l a umbe f l d pools nd field occ r n a m l r o r lated g l g cal en i nment The t m i ed to i d c te the la ge prod cing e g s a h the T as P nh ndle d the M d C t ne t r g o of the Un d Stat

RESERVOIR ROCKS

R rv k re r ks with uff e t p ty a d perme b l ty t llow l d g to ac mu l te nd be p d d n mme al qua t t e Th a th e qu n f rv ro k

inaccurate because the engineer does not have complete data on the various parameters. *See* PROSPECTING (PETROLEUM).

After a pool has some producing history, the engineer may estimate the ultimate production on the basis of curves comparing production against the declining pressure or decreasing rate of production. In gas pools the accurately determined volume of gas produced per pound of pressure decline usually provides a good estimate of future production. However, an unanticipated active water drive in the pool may cause an excessive estimate. A material balance equation gives the most accurate measure of available reserves, provided necessary data are available. Estimates of productive life depend upon estimates of ultimate production and the estimated rate of production, which rate normally decreases as pool pressures diminish. Production rate should never exceed the maximum efficient rate of production (MER), which is the highest rate of production which can be maintained without underground waste. MER is frequently decreased by conservation regulations, by limited marketing facilities, and by delays in effecting unitization or other arrangements necessary for secondary recovery operations.

Predictions of reserves and of producing life are fundamental to the proper management of the field, the financing of the production operations, and the program for exploration in search of other productive fields. [R S K]

Bibliography: R. L. Huntington, *Natural Gas and Natural Gasoline*, 1950; M. Muskat, *Physical Principles of Oil Production*, 1949; S. J. Pirson, *Oil Reservoir Engineering*, 2d ed., 1958.

Petroleum geology

The application of geologic principles in the discovery and development of oil and gas pools. The geology of petroleum includes the origin, migration, and accumulation of petroleum; the structural and stratigraphic relations of oil and gas pools; the lithologic characteristics of formations and producing horizons; and the use of index or guide fossils in correlating horizons.

Geological aspects treated here include the occurrence of petroleum, the character of reservoir rocks, typical reservoir traps, and the general nature of reservoir fluids. For further treatment of the physical and chemical properties of petroleum, the origin and migration of petroleum, reservoir and production mechanics, and geological and geophysical methods of exploration *see* PETROLEUM; PETROLEUM (ORIGIN); PETROLEUM ENGINEERING; PROSPECTING (PETROLEUM); *see also* MICROPALEONTOLOGY; PALYNOLOGY.

OCCURRENCE OF PETROLEUM

Petroleum deposits may be classified as surface occurrences and subsurface occurrences.

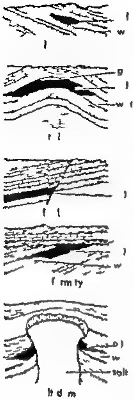
Surface occurrences. These occurrences may be thought of as currently active or live occurrences such as seepages, springs, exudates, and mud volcanoes and mud flows. Others may be termed fossil or dead occurrences, such as bitumen-impregnated sediments, inspissated deposits, and dike and vein fillings of solid bitumen. Another surface occurrence of petroleum is oil shale, a borderline material between the petroleum hydrocarbons and the coal family.

Seepages, springs, and exudates. Petroleum that exudes in any of these forms may reach the surface along fractures, joints, fault planes, unconformities, or bedding planes, or through the connected porous openings of the rock. Most seepages (or springs) are formed by the slow escape of petroleum from fairly large accumulations that have been brought close to the surface and into the zone of fracturing by erosion, or that have been tapped by faults and fractures. Almost without exception seeps are at topographically low spots where water has also accumulated. Oil, which is lighter, rises to the surface of the water, covering it with an iridescent film. Many pools and producing regions have been discovered by drilling near seepages.

Exudates of asphaltic oils issuing at the surface are likely to be changed to asphalt, partly by the escape of volatile fractions but mainly by chemical changes such as combination with oxygen or sulfur. The asphalt is black in color and varies in consistency from a sticky liquid to a substance hard enough to walk on. Outcrops of asphaltic oil are sometimes marked by small pools (less than 100 ft across) which have collected on the surface of the ground. Many of these pools contain the bones of animals that have been caught in the sticky material. Asphalt found at the surface has nearly always seeped up from the bedrock in the vicinity, but there are a few instances where asphalt has been carried by water. Asphalt of natural origin has been found floating in the Gulf of Mexico from Padre Island to Matagorda Peninsula, Texas.

Mud volcanoes and mud flows. These are high-pressure gas seepages that carry with them water, mud, and fragments of rock and occasionally oil. Mud volcanoes are usually confined to regions underlain by incompetent, often shaley, shoulder and submarine landslid deposits, clays, and sand, and unconsolidated sediments. The surface of a mud volcano is often a conical mound or hill with an opening or crater at the top through which issue mud and water which is usually salty. Only the type which emits gas with or without oil in addition to the mud and water should be considered a surface indication of oil or gas. Mud volcanoes occur chiefly in areas of Cenozoic rocks that have been strongly deformed. *See* MUD VOLCANO.

Solid and semisolid deposits. Tar, asphalt, wax, and hard brittle bitumen (any of the flammable viscid liquid or solid hydrocarbon mixtures soluble in carbon disulfide) are popularly regarded as solid, although strictly speaking some of them are highly viscous liquids. Outcrops of solid petroleum are found in the form of disseminated deposits and as veins or dikelike deposits filling cracks and fissures.



Typl l p t l m t p

be u it nn t d harge ts flu d cont t F r a r k t b p m H it mu t ha p r aity inte n t g p e a d po f upe ap llary s ze P l l ty me ed D cy it

RESERVOIR TRAPS

Re erv t ap l tl erv r a th t the a um lated l o g a t pe The pper b d y l i t ap alled th f r p k th l w b n l y ll d th o l wa te t to tabl

R f r p o k an mpervi u layer of rock f rmi g th f of l tr p Th ne t ng pr r n th r erv k ht h e d idually m t a a r le at ted w th wat r S n tl l ga a l ght tha w t the p tr leum th ugh th w t unt l t t pi d by th f k If the o f k a e (dom d h d f ld d pe k d r of h ped) it act a a lly ap g l t

O l wat ta t t bl th low bou d ry f the Ji ally o i ts the t t lly p t f th wat th t n rm lly fill th p e f th rvo ck The w t pp t th p l t l nd g nd the p r of th wat fo tl p t l m pwa d g t th bo d g f f th tr p h ld ng it m pl Th mple t a d m t omm w y f a perme bl de g d f m ti t b m tr p is to be f lded t to a ti li A a t cl f ld (m bl ng i d pl wl) that h upw d ex ty It e b p l d H w ly

th anticline which ha effective cl re with me h riz ntal tent are pr l cti e f il r ga

Geologic structure The ant clinal theory i tl m t uc e f il f ll th theor es f petr le m ge ol g It has l ee timated th t f lly 80 f the oil n th 236 maj r il f ll f the w rll i an an ti l ne The fa t that il and ga mm nly oc ir n anti l nal xe wa f t n ted l y W F Logan in 1842 He l erved that il eps ccurr d in the v c nity f anticl al axes ar tl m uth f tl St Lawr n R er Alth ugh tl t rm anti l nal the ry l s f ll i t di th f nd m ntal pri ipl n wh ch it i l d i till val l—oil and g acc im l t at th eat t g ill l l ght witl in th r ers ir It i r gn z d today tl t th r fa t r ntrol th a m lati n f il in many po l

Classification of traps Three l a i type f t ap ge erally are r gniz d tru t iral traps stratigr pl i tr p nd c m! nati n trap

St uct al t aps A trap wh ipper bo indary ha f een m d con v f y me local d formati n u h a f ldi g faulting (r l th) f tl r r r r k t kn wn a a tr i tu al trap Th edg f a pool cc i ing i a tr ct ir l trap ar d t r m ned f y th int ecti n f tl nd rlying wat r tal le w ll the en l ng roof or c p r ck Stru t r l tr p ncl id cl d ant lin r d m f ulted ant l ne with cl u e cl ure again t fault ti l n downdip des of fa lt d l and g a mul te n i f a t i es prod ed l y t u tu al d f rmat n

St at g aph t p Al kn wn a ary ng per m l l ty t ap tratigr ph trap a th in wh h th h l t ap maki g l me t i m vari t n n the t atig apl y r l th l gy r both of the e rv r rock The e in l i l f c ch g ari ll l al p ty nd p rm l lity a d any up tr tu t rm nat o f th r ervo rock Strati graphi t p nclud a d t e l n es han el bar a d eef p r ty l n es d reserv ir in pe me l le rg nic l d (e al l h le) Som f the m t c mmon tratig aph trap are str d l p l hoe t i g a l t ps l t me a d b h m S FACIES (GEOLOGY)

Str l l ne po l e egi nal f e hanges f om pe meal le t amp m able rocks whi h d term e the l ti n of the dg f n il pool Th y ar o e ll d when oc ted w th hor ph m na S STRAND LINE

Sh t g d t ap are l ng n rr w and depo ts whi h may l n id ed to l e a l l n e f a peci l type They may b half or th q a te s f m le w d nd to ma y m l s n le gth E ept t tl eir t m nal ds th v a m pl t ly u r und d l y mp rv us l les nd la S m a d t aps of th nat i l eliev d to l e h n l fill nd tl ll hore a d l

Tw g n ral cl f ll ma y stratig ph c t aps ur in r k of h m al o ig lm t ll bi herm B tr m s n ly tab ilar por u le th l th f c e r b fa e cl ed or t rm t d by n m l imp rv l l l m

(1) it must be porous, that is, have enough room to store a commercial quantity or volume of hydrocarbons; (2) it must have permeability so that the contained oil or gas will discharge readily when the reservoir is penetrated by a well; and (3) there must be a trap which prevents escape of the oil and gas until they are released by the drill bit. Any rock with these characteristics may become a reservoir for migrating hydrocarbons.

The reservoir character of a rock may be an original feature (intergranular porosity of sandstones), or a secondary feature resulting from chemical changes (solution porosity of limestones), or it may be the result of physical changes (fracturing of any brittle type rock).

Types of reservoir rocks Reservoir rocks may be classified as fragmental or clastic (broken), chemical and biochemical, or miscellaneous. They may also be classified as marine and nonmarine reservoir rocks.

Fragmental type Some reservoir rocks are aggregates of particles, that is, fragments of minerals or older rocks. They are also called clastic or detrital rocks because they consist of mineral and rock particles derived from eroded areas. The constituent particles of fragmental rocks may range in size from colloidal particles up to pebbles and boulders. The most common of the fragmental reservoir rocks are siliceous—sandstones, limestones, conglomerates, arkoses, graywackes, and siltstones. Many, however, are carbonate rocks such as oolitic rocks and coquinas, which are made up of oolites and shell fragments that have been only slightly cemented or recrystallized.

Some sandstone reservoir rocks consist either entirely or in part of loose, uncemented sand grains. The grains are brought to the surface in large quantities along with oil during production. The sand grains in most sandstones, however, are held together by various kinds of cementing material, mostly carbonates, silica, or clays. Some of the cementing materials may be primary, having been deposited along with the sand grains and then precipitated chemically around and between them. Other cementing material may be secondary, having been precipitated from water solutions that entered the formation after it was deposited.

Clastic limestones and dolomites consist of grains of calcite and dolomite that have been transported and deposited just as are grains of quartz. The carbonate grains are made up largely of shells, shell fragments, coquina, and oolites. Rocks thus formed are always more or less recemented with recrystallized calcite and may resemble a chemically deposited limestone or dolomite. Carbonate rocks formed this way are usually good reservoirs for oil because of their porosity.

Chemical types These rocks are made up chiefly of chemical or biochemical precipitate. They are composed of mineral matter that was precipitated at the place where the rocks were formed (in contrast to the transported grains in clastic carbonates). The most important chemical reservoir rocks are carbonate sediments, mostly limestones and dolomites. Some chemically precipitated rocks consist entirely or almost entirely of silica in the form of chert, novaculite, or orthoquartzite, but in some of these there has been a certain amount of secondary cementation with silica. Such rocks are quite common, but compared with the carbonate rocks they provide few reservoirs. The porosity of this type of rock is largely the result of solution, which involves the leaching away of portions of the rock by percolating ground waters.

Miscellaneous types Other reservoir rocks include igneous and metamorphic rocks and mixtures of both. Any porous and permeable igneous rock in close association with sedimentary rock may become a reservoir rock when saturated by oil derived from the sediments. Igneous and metamorphic rocks are only a minor source of oil and gas because generally they are not permeable enough, and when they are, they are not often associated with suitable source rock and a good trap for oil and gas. Porosity and permeability of igneous and metamorphic rocks may result from fracturing or from weathering at the surface prior to subsequent burial.

Marine and nonmarine types A distinction may be made between reservoir rocks which were deposited in ancient seas and those of continental origin. Until recently most petroleum was believed to occur in rocks deposited under marine conditions. Consequently, there was little exploration of nonmarine reservoirs. However, petroleum has been found in sediments of nonmarine origin, such as those in the Uinta Basin of Utah, which consist of freshwater lacustrine marls, limestones, and siltstones. The occurrence of oil in nonmarine sediments is sometimes explained as the result of migration of oil along faults, fractures, or bedding planes from adjacent marine sediments. Further study of nonmarine reservoir rocks will provide important information on the occurrence and origin of oil deposits.

Properties of reservoir rocks The porosity and permeability of reservoir rocks, as well as the nature of the traps, are all factors which regulate the accumulation of petroleum. Porosity is the total space in the rock (pores, voids, interstices) not occupied by solid material. It is expressed as a percentage. Factors which influence porosity are the size of the rock particles, arrangement, sorting, shape, cementing material, and the connate water content. Most oil-producing rocks have porosities above 10% and thickness greater than 10 ft. A rock with lower porosity may prove commercially exploitable if the thickness is great, and thinner rock may be developed successfully if the porosity is unusually large.

Total pore space is not the sole determinant of a petroleum reservoir. A reservoir must also have permeability, that is, fluids must flow through it with relative ease. Pumice, for instance, has a large amount of pore space, but the pores are not connected. Therefore it does not have permeability.

Petroleum processing

Th r e y and p oce t g f ar ous al le fra t n f m the mple c ude l Th u able frac t n n lud ga l ke in l e el l fuel d phalt, l b at ng ls and m ny ther

Th p trol um refi ing indu try is ne of the l ge t m nufa t g indu tr s O r $1 000 000 000 ar sp nt h y ar in the United Stat s f r p tal equ pment ma nt nan a d mode iz t n Alm t $800 000 000 wer p nt in the Un ted Stat for n w eq p ent a d facil t in 1958

The United St tes al n p duc d 3 350 000 bar r l f gasol e p dav (l l l/day) in 1958 In add t n tn f (l w ng prod t wer p odu ed n the q ant t e sh m ddle di t ll te (incl d g ker o n di el o l fuel and other) 2 090 000 bbl/ day e idual fu l l (f r h at g purp es) 1,500 000 bbl/day all other products (including wax e lubr cating oil a phalt c ke and ther) 1 590 000 bbl/day

C ude l is a mixture of many different hydro carl n comp und of th paraffin type (wax c m p und) and f the napl thene ty (a phalt c m pound) making the h mistry f p tr le m re fin ng extr mely c mpl x Th refining proce e can b gr uped under three main heading (1) paratı g the cru de l t rec ver the de ir d p odu ts (2) breaking the remaining large chemi c l c mp und into maller chemical c mp und by crack ng (3) b ild ng the de ir d chemi al c mpound by chemi l reaction such a p ly merizat n r f rm ng alkylat n and i meriza t n

Refinery p odu t uch as ga oline ker ine d e el l and other a e n t pure chemical c m pound but mixtures f ch m c l c mp unds Some f the hydr carl n c mp u d ntained in ga line a e hown in Table 3 al ng with the indi d ial pe ific g avity m lec lar w ight and n rmal b il ng po nt

A implified flow h et of refinery operati n i h wn in F g 1 By mean of di t llati n a typical c ud o l may be s parated qu te ea ily into m ny f a t n of aw pr d ct Some f the e are h wn in Table 4

A m e c mpl x flow heet f a refi ery f r l ght o ls is h wn i F g 2 Here are includ d the cra k ing equipm nt ref rming eq ipment extract n unit p lyr e izat on unit, and th r fa il ties F gur 3 a chemat c d agram f a refinery for p du t ng lub icating oil

Separating the crude oil There a e two prin p l epa t ng pr ce l re not i ol ing cracking —t pp ng f r d l and lubr at ng o l proce s i Both of the e p ce d re in l de c mb nat on f sev ral op rati n h as di t lli ti n ce t i fug ng filtr t n and treat ng pro e

Topp g o d st ll g th c de o l The cru de il d alted and dehydrated then p ed thr ugh h t wl re th temper tu i rai d t al out 650 F t h h temperat e all of th ga ga o l ne ke os n and light f l l f ct ons are in the vap r pha e This vapo and l qu d m t re ent s large d tillat n tower bout ne-third th d w t n up f m th bottom h wn in F g 1 a d 2

T bl 1 R fi g cap cities i the f ee world

R g co t y	R f g capa ty (rud l h ged) J 1 19 8	J 1 19 9 (est)
L ted States	9 800 000	9 998 000
Ca d	810 000	1 010 000
Lat Am n	640 000	99 000
E rope	3 0 000	3 5 000
M ddl Ea t	1 6 000	1 540 000
F E t	1 090 000	1 150 000
Af	100 000	1 000
	18 30 000	0 393 000

W ld O l F b 15 1958
Crud l h g cap t es ba l pe d y

T bl 2. C pa it es f fini g operation

Op t	U t d St tes	F W ld (th th U S)
Th m l k g	1 00 000	3 0 000
Th l f m g	10 000	4 000
C t l t k n	4 1 0 000	1 0 000
C t l t f m g	1 6 000	3 0 000
A ph lt prod t	4 000	80 000
Lubricat l p od	00 000	5 000

P trol m R f S pt mbe 19 8
l ba rels pe d y J 1 19 8
Accura d t l bl f th C mm t
W ld

T bl 3 S m h mical mpou ds f nd i g l n

N m	F rm l	Molec l we ht	API gr ty	N m l bo l g poi t F	R sea h oct n mbe
P tan	C H	7	9	97	6
H	C H	86	81 6	158	6
H pt	C H	100	74 1	09	2
n Oct	C H	114	68 7	260	0
N	$C H_{20}$	1 8	64 6	310	−19
Decan	C H	14	61 3	343	−34
F decan	C H	1 6	58 0	387	−53
					−60

O ly th tra ht-ch p aff hydroca bo re h wn b t di t th r ge Act lly th g ol n co t in l o l nel d-ch paraffi lke es n phth nes rom t cs d oth compou d

stones or dolomites Bioherms or organic reefs are porous domelike moundlike or otherwise circumscribed ma es built exclusively or mainly by edimentary organi ms such as corals algae brachiopods mollusks or crinoids and enclosed in normal rock of different lithologic character *See* BIOHERM BIOSTROME

Combination traps The e traps re ult from both structural and tratigraphic conditions An exam ple of uch a trap is the salt dome Salt dome are cylindrical or teeply conical mas es of rock mate rial which were forced to flow plastically under heavy pressure These ma es called plugs or domes originate at unknown depths and pierce the overlying sedimentary strata Three kinds of traps are as ociated with salt plugs cap rock flanking and and supercap sands Cap rock consi ts of calcite gypsum and anhydrite and occurs as a cap ping over the tops of the salt plugs Flankin ands are strata abutting upon and cut off by the alt plug Supercap sands are sandy strata that arch over the tops of the plugs in the form of structural domes *See* SALT DOME

RESERVOIR FLUIDS

Fluids fill the voids or pore paces in all reser voir rocks The fluid may be water water and oil water and gas or a mixture of water oil and gas The fluid content of a gas pool con ists of water and gas that of an oil pool consi ts of gas oil and water There is almo t an infinite ariation in the compo ition relative amounts and propertie of these fluid in various reservoir

The distribution of gas oil and water in the res ervoir depends upon relative buoyancy relative saturation of pore space with each fluid capillary and displacement pressures as well as the po os ity permeability and compo ition of the re ervoir rock In traps that contain gas oil and water the fluids take on a zonal character Gas bei g the lightest fills the pores nearer the top of the trap Below the gas there is a zone in which the pore filling liquid is chiefly oil and below that water alone occurs the contact bein the oil water table Where there is gas but no oil the gas is immedi ately underlain by water and the contact is the gas water table Interstitial water (ad orbed water or wetting water which lines tl e pore walls) is pre ent throughout the re ervoir occupying from a few to about 50% but generally between 10 and 30% of the pore space The amount of interstit al water in a petroleum re ervoir is commonly meas ured in percentage of effecti e pore space and is kno vn as the water saturation

Oil field waters are waters a sociated with oil and gas pools They may be classified as meteoric water connate water and mixed water Mo t oil field waters are aline except at hallow depth *See* OIL FIELD WATERS

Oil aturation i the amount of oil contained in a petroleum reser oir It is measured a a per ent age of the effecti e pore space

Gas volume or natural gas content of a petro leum re ervoir may range from mall quantities di solved in oil up to 100% of petroleum content

Natural gas may be cla sified a a sociated when it occurs with oil and as nonas ociated when it occurs alone The natural gas in a re ervoir may occur as free gas as gas dis olved in oil gas di solved in water or as liquefied gas *See* NATURAL GAS OIL AND GAS WELLS PETROLEUM RESERVOIR ENGINEERING [D D G]

Bibliography G D Hob on *Some Fundamentals of Petroleum Geolo y* 1954 C G Lalicker *Principles of Petroleum Geolo y* 1949 K K Landes *Petroleum Geology* 2d ed 1959 A I Levor en *Geology of Petroleum* 1954 W L Ru sell *Principles of Petroleum Geology* 1951 E N Tiratsoo *Petroleum Geology* 1952

Petroleum microbiology

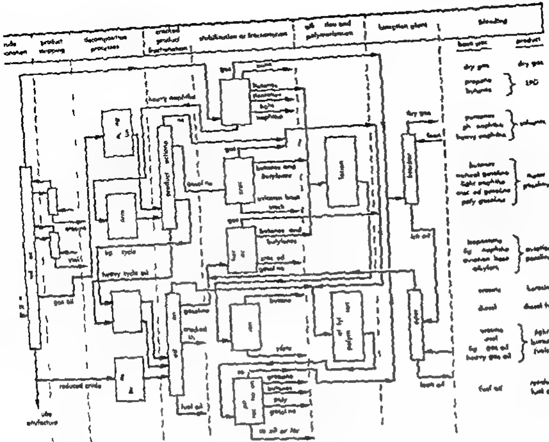
Those aspects of microbiological science and en gineering of intere t to the petroleum indu try in cluding the role of microbes in petroleum forma tion exploration production manufacturin and torage

Petroleum formation Dead marine microor gani ms compri e much of the edimentary mate rial from which petroleum is formed Otl er bac teria such as *Pseudomonas Achromobacter Desulfovibrio* and *Flavobacterium* specie modify the organic nature of this material The extent to which they actually convert organic ediment to petroleum hydrocarbons is uncertain becau e thi ha not yet been demonstrated in the laboratory

Petroleum exploration Many microor ani m are able to employ hydrocarbons as a carbon source conve ting them either to carbon dioxide and water or to intermediate organic compound The so l above a petroleum re e oir may contain ga eous emanations such as methane and ethane from the reservoir and it is belie ed that the e may be detectable by the c ncent ations of certain hydrocarbon utiliz ng bacteria (*Methanomonas* pe cies) in the soil o by tl e growth of si itable cul tures planted there Such exploration techniq ies have been intensi ely inve tigated but tl eir uc ce s remains que tionable

Petroleum production Mi oorgani ms (*Crenothrix Beggi toa Pseudom nas*) a e f eque t and costly contami ants of drill ng fluid nd f ec ondary reco ery injection waters and chemical agents like formaldehyde and quaternary am monium compounds are nece a y f r their co trol Bacterial co rosion of ron pipe pa ticularly buried p pe by *Desulfovibrio* pecie is a major problem in the petr leum i du try It i gen rally treated by protecti e coatings or l y c th d c pro tection Bacterial dete ioration of refine l petroleum products in storage of a pl lt and a phalt coat ing a d f oil emul ion u e l w th c tting m chinery are al o ind strial prol lem [E J BF]

Bibliog aphy E Beer tech r Jr *P trol um Microbiology* 1954



2 Sh m t d g m f ef ry f lght f (m hy g l k d d tll t st

f sol e t by steam t ppi g r u m ı g Q t ft tl s l t m xp th l be n t ated so th t fr m the t d ıt f my l n all f the l e t m st b d M mp rt ntly th l nt t ll m y p perti d t m t l the fi hed l when t n tra m nt t llat All d t ll t p es r e s) the m Th f t r t b e ns d red f t t pes f d t ll t proces es lud th t ty f l q d w th pect t h at, tl e pe fi n f th p od t, a d th bo l ng ang f th f

t f p k mm g p ed tes the d ted t a rt t mp t nd fed t a d t l t h th p od t f ct n e e ed t h ghts l g th ol mn F g l l d h m t d g m f h t

t b l zat th d t ll ti p es that r th l ght h d bo (s lly the d s ed g eo h d oc b n) f m the p t c l t l g p o es l H the f ed ı l ted tı fr t n tı c lumn wh ga e ed h d nd th t b l zed pr d t at the t m l ı l ga l e t b lız 40-60 plates q ed ı th d ıll ı f mn t r m d l ed p p n d l ght b dr a b l t b l zati f p es ed t ll t th f ed ı ted ı m h h gh t mpe t r s c l p o d h t e t

Ste m d t llati n ı u ed t ın re e tl am unt f d tılled p od ct bt n l le at a fixed feed tem pe at e Th f ed t k heated t app x matel 550-660 F ı the pres n of a la ge am unt of te m Th eff ct f te m t red ı th b ıling p ı t by p rt al p es ure effects The boiling point f m ter al c n be r du ed eıtl r by r duc ng tl e t t l p essure r by dd ng a t ert g s a ch that the ame total pre e will be part ally due t th e t g s

V c um d t llati n u ed f the red ı tillat n f th pres te d st llate lube stock *topped crudes* nd the f a t on Lubricat ng o l f ex mpl ı th rm lly n ıt and pa t ally dec mpo f ex p ed t l gh t mpe tures Theref th d tılla t n d n u d a hıgl a m t take ad tage f th l w r tempe tur s *requ* d t the lower p at g p Sometimes h gh u m s ot ffi e t nd ıt n ary to omb vacuum d t ll t o w th t m d t llat n t a mb t on ıt l th s a team ı dd d t th d ı ll t n c l m pe t g *und* th acu m The am unt f t m r qui ed w ll ry f cou b t m y b h gh l o 2 lb/g l f ıl p ed The d y *um d t ll t* p oces es h the ad nt g th t sm lle t we s r q d f g ı th ugh p t In add t n malle e d n ng equ p me t ı qu red

C f ug t n The e tr ing ng p ces fo de n ıng lub st cks l e ng epla d rapidly by ol e t d wa ıng p o H y m ny cen

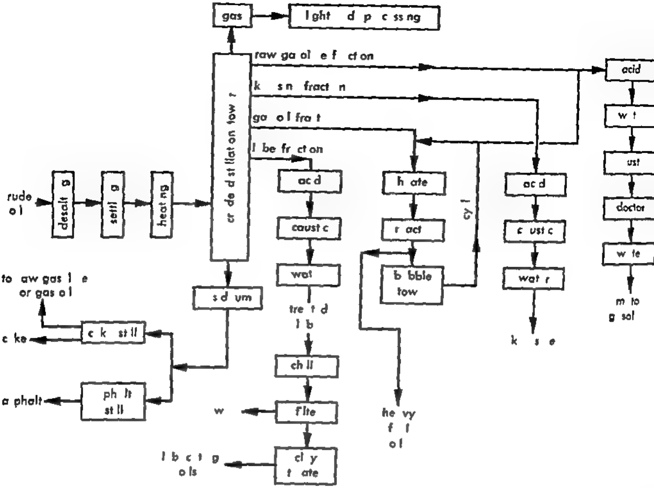


Fig 1 Simplified flow sheet of crude oil refining

Into the bottom of the tower about 1–2 lb of steam per gallon of crude oil are usually introduced to make the separation easier From the top of the tower some gases are evolved and sent to units processing light ends The next higher boiling fraction is the gasoline followed successively by the kerosine the gas oil the cracking stock and the lubricating distillate Below the feed entrance a fraction called the residuum is removed

The temperature of the feed to the tower depends considerably upon the ultimate plans for the residual oil If this residual oil is to be processed further for the manufacture of lubricating oils the feed is not heated to so high a temperature

Each of the streams from the distillation unit must be treated further before it can be sold The gasoline fraction is treated then blended with other stocks Finally certain chemicals called additives are added to the stream to improve its properties *See* DISTILLATION FRACTIONATING COLUMN

Table 4 Some fractions obtained from crude oil

Fraction	Carbon atoms	Molecular weight	API gravity	Boiling range, °F
Gas	1–4	16 58	0 38 0 58	– 9 31
Gasoline	5 [illegible]	7 [illegible] 1 0	58–6	31 400
Kerosine	10 16	156– 6	40–46	356 5
Gas oil	15	[illegible] 94	35 38	500 00
Lube oil	19 5	68–49	[illegible] 30	610 8
Residuum	36 90	49 1 6	8 18	8 +

Lubricating oil processing The most important property of lubricating oil is its viscosity The lube fraction produced in the vacuum distillation column contains some hydrocarbons that give the oil a poor viscosity temperature characteristic In addition the lube oil fraction has poor oxidation resistance and contains wax and other impurities which must be removed Consequently the lubricating oil fraction must be treated to remove or to reduce the concentrations of the following free carbon forming material low viscosity index material wax unstable compounds which may decompose to form asphaltic substances or coke and chemicals that affect the color of the lube oil product

The flow sheet shown in Fig 3 describes a process for the production of lubricating oil Not only the lubricating fraction but also a portion of the residuum fraction is used to make the lubricating oil In this case the residuum is treated with a solvent to remove the asphaltic material The deasphalted residuum is further extracted along with the other lubricating oil fraction dewaxed and acid treated clay treated blended with additives and then sent to storage

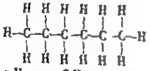
The solvents used for deasphalting include furfural cresylic acid phenol sulfur dioxide chlorex nitrobenzene propane benzene and many others Since the solvent must be removed from the oil after the extraction further distillation equipment is required The oil are freed from the [illegible]

ca bo f rmat an l ga l f much higher octa n mbe

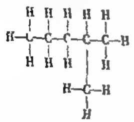
About 80% of the c acking capac ty in u the U ted St t s t day of the t lytic type See CRACKI G

Rebuilding the desired chemical compounds Th atu ated t ght ch in p affn hown in Tabl 3 ha e ry l w cta numb r Th om p nl a b alte ed h w e by chemical reac t to y eld a diff nt k nd f mole ul w th m h h gh r cta e character tic In g n r l the t ght p ffi c mp d ha e th lowest octane r t g d the m t e mpo nd (benz ne f m ly) h the h gh t Th l fin d the n ph th es h nt rmediate t ne ml r

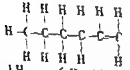
B l wa e m f the f rm f a i -ca bon at m hyd oc b n and th e e r h octa e numbe (RON) All th f rm a d m ny other r f d n the g l e f ct n It p bl t n t h x ne (RON 24 8) nt be z ne which ha o ta numb r f o 100



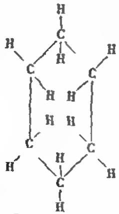
n H a e C_6H_{14} (t ai ht h pa aff) RON=24 8



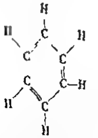
2 Methylp t n s h a C_6H (b an hed paraff n paraff) RON = 73



1 H C_6H (l fi alk) RON = 80



Cy l l ex $C H_2$ (phth n) RON = 83



Ben C_6H (m t c) RON = e 100

Amo g th ma y p oces es u ed f k ng th h m l t u i f th m lec les a e th f ll w g

1 Hydrogenati n i u ed m tly for produc ng aturated hydroca bon fr m un aturated nes Du ing World War II this pro e wa u ed f r mak ng ooctane fr m iso tene M re recently th s pr es has been u ed alm t excl ely for d i lf r zat on pr ce

2 Dehydrogen t o is th r mo l of h dr g n from a molec le F r xample l he ene may be m d fr m n hexa e Th s react ft r It in inc e ed ctane n mb er

3 Ar matizati n yield a omat t pe hydr car b n fr m ther type a l nz ne fr m h x n y l hexane Ar matizati n a d omerizat n p e d minate n th e reform g op r t n

4 Cyclization i the t an f rmat n f a l d o- carb f th ch a n t pe t f th ring type for ampl maki g methylcycl h ane from n h pta

5 I me izat on the rearrang ment of the atom i a m lecule ch a n hexane t f rm an isome u h a i he ane In 1958 th i m riza t n apa ty i the U ited States refin ng ind tr wa about 30 000 bbl/day f t thi pr mi t le a rap dly e pand g proces in the indu t y

6 Polymerizati n in l es tw or mor m le cul n a bu ld ng p oces For exampl pr pene and the b t ne wh h a e present in th ga es f th rmal r c t lyt c-cra k ng operati n are poly m riz d to f m a la l quid m l ule w th a high ct e n mber

$CH_2{=}CHCH_3$ + CH CH CH=CH $\xrightarrow[\text{catalys}]{\text{Hea}}$
Pr pe 1 B ten

$CH_2{=}CHCH_2CH_2CH(CH_3)CH_3$
5 Methyl 1 h en

At the pre ent tim th c tal tic polyme izat n ap city in th U ted St tes i ver 140 000 bbl/day

7 Alkylat n al mak u of two more mol ul n the act Th pr s an o- pa affi ch a but ne, a d an l fin h as th le e to y eld a l ger m le ule w th a h gh cta e numbe 2 2 dim thylb t e i th s ca e

$CH_2{=}CH$ + $CH_3CH(CH_3)CH$ $\xrightarrow[\text{catal}]{\text{H t}}$ $CH\,C(CH_3)_2CH\,CH_3$
Ethyl I ob tan Dim thyl but n

Th s eat t n s ly n h lf a m ny of th x F t e ol fin m l c l s s th p lym zat F I 1959 th lkylati ap c ty n the U t d States a 360 000 bbl/day Th als a f t g w n p t f the refin n indu try S ALKYLAT ON ARO IATIZATIO HYDROGE A TION I OMERIZAT ON OCTANE UMB R REFORM I G (PETROLEUM REFINING)

Treating processes Both the c ud il nd the p t l m p duct m t n o c l t ated to r mo unde ble mp it es to imp the

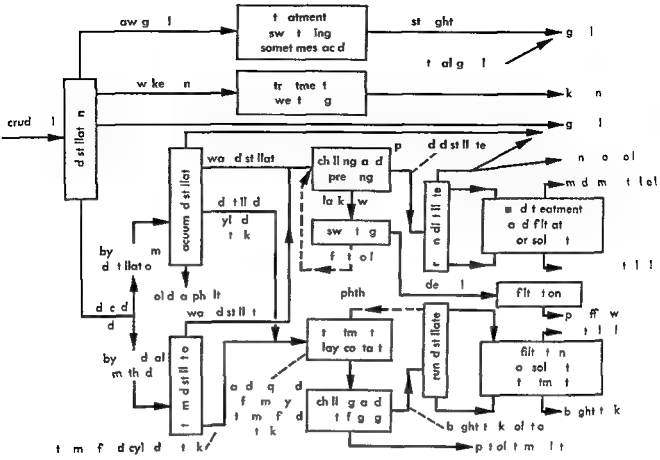


Fig. 3. Schematic diagram of a refinery for lubricating oils (from W. L. Nelson, Petroleum Refinery Engineering, 4th ed., McGraw-Hill, 1958).

trifuging processes are still in operation. In this process the lube stock is mixed with about 50–80% naphtha and chilled to some low temperature. If the pour point of the finished oil is to be 20°F, then the stock is chilled to approximately −10°F; for a pour point of 0°F it is necessary to chill to −40°F. The cold solution is fed to a centrifuge where the wax is separated from the oil. The capacity of one of these centrifuges may be as high as 75–100 bbl/day of oil. The centrifuges operate at around 16,000 rpm and require approximately 1 kw of power. See CENTRIFUGATION.

Filtration. This is also an important operation in the refining of petroleum. Regular gravity type settlers are used wherever possible, but occasionally the solids are too finely divided to settle. There are many types of filters used for the removal of finely divided clay from treated stocks in the clay contact process. These filters are classified as filter presses, leaf filters, rotary filters, and others. See FILTRATION.

Breaking the large molecules. The major product from the refinery is the motor fuel (gasoline). Of course, kerosine, diesel oil, jet fuels (mostly kerosine fraction), and others are extremely important also. However, each barrel of oil charged to the distillation tower has a given fraction of gasoline. This varies, but on the average is not over 20% of the total volume of crude. If more gasoline than this 20% obtainable by distillation is desired, and it almost always is, it is necessary to resort to other means than straight separation to get more gasoline. This can be done either by recombining the gaseous or lighter molecules (polymerization) or by breaking down the heavier molecules (cracking).

Cracking. Table 3 shows that gasoline molecules seldom contain more than 11–12 atoms of carbon. The crude oil, however, contains many molecules consisting of more than 50–60 atoms of carbon. The heavy naphtha fraction and the kerosine and gas oil fractions, for example, all contain large molecules compared with the gasoline fraction. In order to use these fractions for gasoline production, the long or large molecules must be broken into smaller ones of the gasoline type. This process is called cracking.

The cracking may be done either by thermal means (maintaining the heavy fractions at high temperatures) or by catalytic means. In thermal cracking the charge stocks are usually light and heavy gas oils, residual oils, or any of the topping column fractions heavier than the gasoline fraction. The resulting gasoline yield depends upon the composition of the charge stock but will range from 15 to 40% by volume of gasoline (100–400°F boiling range).

In catalytic cracking the fraction to be cracked is contacted with a catalyst at lower pressure conditions than in thermal cracking, although the temperatures are still almost as high. Catalytic cracking gives much better yields of a

ra ge from 200–600 F d pe d ng on th natu e of the g al ıl) Th propane, mo ture and reac tion pr ducts are rem ed ın a acu m tripper a d the l ooled and filt red The ıl s e t thr ugh add t o al flt r ng operation and then to to ge Befo e th l ı sold add t are add d t g e th ıl tan de r ed p operties The clay ı e ct t d ın a cl y regenerat e fur a e S e ADSORPTION

Vapor phase treatment In th pr ce gum f rm ng mp und n the gasol ne vapor are re m ed by ad rpti n nt clay mat r l It ıs a low c t tr atment a o er 25 000 bar els ca be t t d pe t n of clay before clay rea t at on nece sary The y r f m the u ack n u ıt ente th tr at ng t w r (oft e lled p lymerizer) ea the t d flow d wnward th ough a pa ked cl y b d P lyme zat c r n th tower and a p lym r l q d ta n g la ge pe ce tage f g l ne coll t at the b ttom The vapo pa t the ndenser fin h d ga ol ne c pt l r the swe t ın pr e The polymer ı dra ne l fr m the towe and the gas line e o er d ın ep r t t er

The u of gum ı h b to s ha to a gre t t nt b te l th ap r pha t eatm t

S l nt t tm t n pet l m ef g Unde d e n t t ents m y lso b r mo d by le t ol t e tra ıı n l th s c e l q ıd th t ıll elect ly d sol e th ınd ed c titu nt ı add d t the l Th l nt p oces es may be d d d nto tw m ı at g l e t xtr cti nd l e t d w x n

Th sol ents d ı the e ı a ı n p c es ı l d the foll wı g p p e and resyl c d 2 2'-d hl rod thyl the ph n l furlu al ulf r d ıd ben e d n t ob nz ne

I th dew x g p th p c p l solv t a e b methyl thyl ket ne p p p t o l um phtha thyl ne d chl rıd a d ulfu d x d

Bef r the s l ent xtr cti n pr e w de lop d, nly f w type of crudes were on d d to b g d lub atı g ıl crı d By ng th sol nt p th o ıg l p pert f the d b h g d gr tly th t alm t a y rude w ll m ke g l l bric t ng o l

The lv d lopm t f *sol ent* p c ı g w ed w th the lub at g l end f th rude Solv t e t a t o p c e be g ap lı n f gasol ke o ne d l f l a d th r l dd t n sol nt ext a t on may r pl c f a t atı n n m ny at n p c t th re fin ry F xample, p p dea phalt ng ha e pl c d t om e t t a ım t llat n s a m a f r m ng a ph lt fr m du ed nd S SOLVE T EXTRACTION e al OIL ANALYS S P T HES IC L PETROLEU I PETROLEU I PROD UCTS [J J M]

B bl g phy W L Nelson *P t leum Refi y F g* 4th d 1958 *P t ole m R fin P D lopm nt* p bli h d S pt mb r dd numbe ed years *Petrol m Refiner Process Hand book* p bl hed S ptember e en numl ered years P A W l er *Fund mentals of General Refin ry Practic s*

Petroleum products

M t r de petr l um s u ef l only as a raw ma te ıal for the manuf cture f l rge numl er of p od cts uch a fuels lubricants pa ıng material and ba e compounds for ch mıcal manufacture It ıs not un al for a large o l mpany to lı t 200- 1000 prod cts f r s le

Major products A n rmal cr de oil will c n n thou nd f hyd o arbon ra gıng ın m lec ular we ght from that of *meth n* CH the *chief* onst t nt of natural with molecular w ıght f 17 t tho e of a phaltic c mp und with appar nt m lecula we ght of b ut 50 000 100 000 *During* r fınıng such a crude ıl fir t d t lle l ınt frac tı wh ch e er *ts b ıling* po nt range The l w e t bo lı g fr ct o s ar the normally e s hy drocarb s methane ethane prop ne and the butan s Meth a ıs u ed a a f el the other a e u ed h m cal raw mat rıals r a e n titı ent *of liquefied petrol* um gas old ın lın ler

The hyd oc rl ns f om p nta e to dodecane (C_5 to C) g nto ga ol ne mot r fu l and thı pr d u t ın all ıt var t t ke ab ut 45% of the c ud l pply f the w rl l Gasolı e f r r cıp r at g e gı e c er a c n derabl range of ch mı al c mpos t *on* w th co re p nd ng arıa t on n pr p rt e the m re important l e *ng vola tılıty* a d re stanc to k ocking Mın r e of ga l n hydr carbo r ga ette l ghter fluid pot remo s dry-cl a e naphtha and paint l t

Anothe 45% of the rude ıl ıs u ed also f r f l m fact re ke o ne f r lamp and st l el engı es a d h e-heat g furna e tuı tu e f ga l n a d ke s n f jet eng nes g s o l f r die els h se he t s a d speci l and trial job h avy re dual ıl f r team g t on f r p pell ng h p and fo hea y ındu try uch as c me t a d te l manufactu e Th c mp ıtion of the hydroc bon ın k r erlaps that of th h y d f the g l e f ıı n ı hydroca bo c nt nt l ng at b t C to C th hyd o- C to C nd he vy fuel o l may c nt ı hydro- a bo up t C o C A ph lt are c mpo ed f t ll m r e mpl x and es ent lly on olat le ub t nc s togethe wıtl c mplex c mp und f lfu nıt gen nd xygen wh h are l g ly hydro b ın haracter

Minor products The ab v maj p du t mak up 90% f th tp t of the ıl ı d t y The m ıng 10% s d d d ınt a w de a ıety f mat ıal th mo t ımp rt nt beı g the l br a t Th e xtend f om very l ght, l w t l qu d empl yed f r h gh sp ed ma h ery u h s sp n g nd wea ıng eq ıpment th ugh e y s o ls fo e ıpr atıng t m e gıne t mı olıd d e n l d l b t ng grea es

properties of the product The important treating processes are desalting and dehydrating sweeten ing and desulfurization acid treatment clay con tact ad orption treatment vapor phase treatment and solvent treatment Some of these proce es are used both on the crude oil and on the products whereas others are u ed on only one or the other

Desaltin, and dehydration of the crude oil The salt content of the crude oil which enters the re finery may be as high as 4 or 5% and the water content may be much hi,her than the equilibrium amount because water is pre ent as an emulsion

Becau e of the hi,h temperatures of the heater tubes the introduction of the wet crude into the heaters would be dangerous In addition the salt would precipitate onto the tube walls reducing the rate of heat transmi sion and thereby the efficiency of the heaters

Many proce e are available for the removal of both the salt and the water from the crude oil The e are grouped into four types as hown in Table 5

The crude oil (containing the salt and the oil) is heated an emulsion breaker is added and the resultant mass is ettled or even filtered to remove the salt and ater phase from the oil pha e

Sweetenin and desulfuri ation Since the ori,i nal crude oil contain some sulfur compound the resulting ga oline and other products also contain sulfur compounds includin, hydro,en sulfide mer captans sulfide di ulfide and thiophenes

The proce ses u ed to sweeten or de ulfurize the products depend upon the type of sulfur com pound pre ent and the specifications of the fin ished ga oline or other stocks

Mercaptans are removed or conve ted into less undesirable d sulfides in these ways

1 Mercaptan removal (*a*) Uni ol process uses an alkaline olution of methyl alcohol (*b*) Solu tizer proce es use odium hydroxide along with minute amounts of sodium isobutyrate and (*c*) Mercap ol process uses an alkaline solution of naphthenic acids and phenols These are regenera ti e olution processes

2 Mercaptan con er ion (oxidation to disul fides) (*a*) lead sulfide doctor sweetening (*b*) copper chloride oxygen sweetening (*c*) odium hy pochlorite sweetenin, and (*d*) copper sweetening

3 Hydrogen sulfide removal by regenerati e o lution proces es using aqueous solutions of the fol lowing (*a*) sodium hydroxide (*b*) calcium hy droxide (*c*) trisodium phosphate and (*d*) odium carbonate

Catalytic desulfurization is u ed to convert the sulfur to hydrogen sulfide which is removed later by one of the above proces es

Acid treatment This proce remove the color ing materials from base stocks Lubricating oil made from paraffin ba e crudes do not require acid treatment while distillate from the mixed and a phalt types of crudes generally are refined with acid A 93% solution of sulfuric acid (66 Beaume acid) is most commonly used in acid treating Sometimes a more dilute acid is u ed pecially when treating done for color removal only oc casionally a 98% acid is u ed for lubricating stocks

The amount of acid u ed will vary with the type of crude and with the specification of the product For example (1) natural ga oline 2 lb of acid per barrel of product (the process i commonly run at 70–90 F) (2) straight run ga oline 3–5 lb of acid per barrel of product (70–90 F) kerosine up to 20 lb of acid per barrel of product (90–130 F) lubricating oils 0–50 lb of acid per barrel of product The oils from Pennsylvania crude re quire little or no acid treatment mixed ba e crude up to ?0 lb/bbl and the asphaltic crudes require up to 50 lb bbl (120–180 F)

The acid and the product bein, treated are agi tated o that there i intimate contact between them Some of the acid treatment proce ses require 1 minute or le s of contact time bet een the acid and the material be ng treated Kerosine may re quire as much as 30 min contact time while the lubricating stocks may require 1–2 hour Continu us proces es are in use today and contact time i bein, shortened considerably

Clay contact adsorption treatment The u e of clay treating fo the purification of oils was known as early as 1822 Percolation filtration was ideally suited for the slight decolorization required by the Pennsylvania oils The term percolation is applied to the filtering method in whi h the oil i pas ed through a bed of granular ad orbent clay

Contact filtration makes u e of a direct agitation of a ery fine clay with the o l at elevated tempera tures for a gi en time

Dur ng the clay treatment the oil are neutral ized and decolorized by the remo al of the sus pended matter The decolor zation f il i an ad sorption proce in which th a phaltic and resin ous chemicals of the oils are ad rbed on the sur face of the clay part cle

The oil i mixed with the clay in the ratio of 20–80 lb of clay per barrel of oil (that i fr m 5–30% of the weight of the il) The omm ly u ed clays are fuller earth l ento ite l uxite and alumina and acti ated alumina

After the oil and clay are mix d the lurry formed i ol ent treated using prop ne a l ent After l ent treatme t the resultant mixtu e i heated to the treating temp ratur (which ma

Table 5 D s lling and dehydrat ng methods

M thod	T mp t F	Typ of t tm t
Ch m l p t	140– 10	0 0 –4% l t f so p w t 0 5 % l t n f od ll w t
Fl t l p t	150– 00	10 000– 0 000 lt
G ty p t	180– 00	Up t 40% w t d led
C t f g l p t	180– 00	Up t 0% w t dded (som t mes n w t d l d)

All p t leu xcept the c den at ers de (e y l ht des rr d a apor m d ep hi h p u e g rv ı } t in l ib icat ng l ma te l f t the l wer g ade c ude f r exar ple th l the Middle E t ar ntam nated with a ph lt c mat al and omp und of ulfur and n tro n h ch use d ffi ulty and l in efining Good l b cat ng to ks an be mad fr m uch c d th fa m mv u g d fferent al ol ent e t act n

Bef e th l el pment f ol e t extra ti n m thod nat al petr leum wer f red for the p odu t o of lubricating oil b t tl y ba e unde rabl ch a te i ti wh h h w up u d r e er o e at g nd t M d n l br c nt co t f a bl d of refin d p t leum pr duct uppl n nt d b addt e ant o idant anti o r n agent d per t d t rgent mpr r of i n ty tem p t haracte t a l so Wh e l q id l l r a t t erve oils th k ed with ap of sodi m cal m l mi um and l thium or with ol ophyll lid —mod fied l a a d bentonit s —a yl yel

Nat e a ph lt are ar ly ti fa tory for u e Th y re lte m e pen s than th e mad f m p t le im wh h ha la g ly pla ed th n t mater l h u e th p p rtie ca be m p lat d b ele ti of uit ble crude oil and by e king d l ll t on by o dat on t high temp r t b ble l nd b n e f add t es Th q ant t f pl alt empl yed for pa n r fi nd m ki m ld d a ti les a e the rat 2 1 1

Pet le im w es o d m th mak g f l br ting o l from paraffi r d f ll m tw l (1) f d w x mae ocry t lli e m t pe e ent ally th n m l paraffi C to C u l i dl p p r w x ng and ho eh ll ra ffi w and ( ) m r crv t ll e wa s the am rph r of omm e ed widely pa p r zing t at ng f zen f od pa k ges n n l ti d m k g p t lat m

Small q t ti f p tr l m r u d to mak h n al h t l m l th lion t n ul t ing l m t d bb st nd hyd g n d t y thet c d te g t an l ntermed f th h m al indu tr Th aw mate al good d al b s t ken l rgely f om the h a e f t n f th d)

See sep t rt) th m n p t nt p od t l As HALT A SPH LTITE GAS o f l B v PE OLEL PET O E M ROC r NG

[M SO]

Petroleum reservoir engineering

Tl ppl ed r d w th th de l p m t a d n t n f r rs f ra m m f ol g both It m pe t l l g e g d n ted ppl t f m pect l t f di pl h s pl geol gy hem try nd m th m t ll a th e g r g sen m th t dy of tl pl m y t m

Th gro m a ure f a r rvoir a an entity f mm rcial int re t are (1) the amc int l o l ga r b th m tially p e ent m the re ers ir (2) the rat at whi h tl e hydrocarl n can l e withdrawn and (3) the fracti n of the rig nal l ydr carl on m pl e whi h can be conom cally rec ered

Oil or gas in place Tl e am int initially m plac can be d term m d imply a the l m f r serv ir ck nta m the h dr arbon f m terest tım the c nt nt per t nit v lum of rock The former can be obta ed l y the tl ickne l th productive l rmati n at well drilled for it d lopment a d the t tal productive ar a def ned and tl ned l y the e w ll The il or ga content per u t lum of rock nl ally g ven by the m ured calcı lat d p ro ty r d ed by th amount of wat r at irati n fr n tl re rvoir l me of th hydr carl n the v lume at the ur f e an l e calculat d The two l m liff r l e- cau of hrinkage f rude il on e l iti n of it l tion ga s expan i n l fre r ers r ga a t pr ure decl es t atm ph ric The f rma tion thickne p r ty and c nnate r int r titial water at irati n h ld b con der l lr ally ar able to tl e extent tl at ch vari ti n an l determ n d fr m inf ormat n obta ned at th in d v d al well

If the t tal m a ured cıl b a ing r pr d icti e a e in acre i ind c t d by A th a erage f r a t n thickne of the produ t e z ne excl d ng n np oduct e membe uci a hale in f t l h th a erage por ity by φ the erage wate at ration by S_w and th formati n v lum f ctor of the o l by B the initi l u face (tock tank) oil content i pl ce N will be gi e by the quat c n

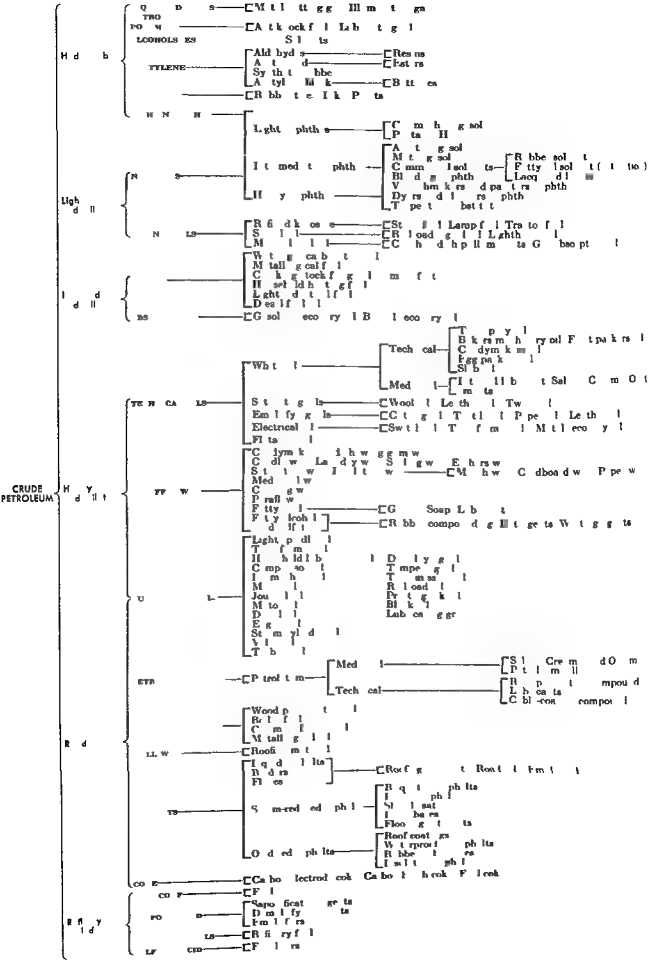
$$N = 58\,44 h\varphi (1 - S\ )/B \quad \text{bar el} \qquad (1)$$

For the ga cap f an v rlying o l re rv ir r a n nas o i ted ga er a the ga cont nt wo ld be d t rm n d by th ame qu ti n p ov d d the term B repl ed l y B the olume at re erv ır c nd tion of a unit l m f ga t the s rf c Th ga ntent in ub f t t bta ed by m lt ply ng th lc l ted lum n b rel b tl f to 5.6146 F r a c mplete ac u ting of the ga nt nt th t d l ed n tl e l (the lit n ga) s al ulat d as tl l c ntent times the gas olubil ty at the nit l c d t n expre d a c b fe t pe bar l

The material balance equation Th in tial il n pla e n al be nf r ed f om ob ervatio s the r e beh or within the r rv a l a d g a e produ d Mak ng a mat rial b lance f the g s nd oil by int rr lating the v l m p odu d w th th mou t a um d t b n tally pr nt it f und th t N w ll be gi n by th materi l b lan e equat n

$$N = \frac{N\left(\frac{R - R + B}{B}\right) - C - \left(\frac{1}{B} - \frac{1}{B}\right) G - \frac{W}{B}}{R_m \quad R - (B - B)/B_g} \qquad (2)$$

Crude petroleum and some of its products



From P Albe t W T A d M Coll ge F t D (Fra Season)

All pet l m exc pt th c nd n at c u le { ery l ht cr d a rt d a vapor in deep h h pr r g ree) t n l ibr c ting oil ma t al b t th lower gr de cru l f r example th f the M ddl Ea t ar ntam at d with a phalt mate i l and c mp unds f ulfu and nit en whi h e d ffi lty and lo s in refining. G od l b t ng to k ca be m de fr m u h c udes w th f r e n my us ng d ffer nt l l nt t a t on

Bef e the de elopm nt f solvent tra t o m thod at l pet ol ums w re fa r d f r th p od ict f l br at n l b t th y ha e und able ha t t e wh h h w p d r se pe at ng nd t M d rn l br ant co t f bl d of refin d pet le m p od ts supplem nted addit —ant ox d t nt r o n ag nt d pe ant d t rgent mpr e s f i c ty t m p tu e l a te t and so on Where l quid l b nt a not erve ls thi ke ed with p f od um al um lum num a d lit um or w th le phyll f d —m d fi d s l as and bent nit ar n pl y d

Natu phalt are rel t fa t ry f z Th y r ft m e p s th n th e mad f om petr l m h h h y larg ly y) c d the at e m t r l h a the p ope t s a be man p lat d by select f u t l l r de l nd by on r k ng d till t n by ox dat n t h gh t mpe t r b bl n f g a d by f add ti e Th q t ti f a ph lt empl d f p n oofing a d m k ng m lded t cl e in th r i 2 l l

P t l m w d n tle m k ng l lubr c t g l f m p r ffi i ude f ll n tw l (1) fi d w x ma ry t ll e in typ t ll th l p ffi C t C u ed n lle p i w ng, and h hold p ffi w a d ( ) m r ry tall a th m ph u w x f mm e u d w d ly p p izi g i t n f oz f od p kag in n lat n n f m k g p l) tum

Sm ll qt i t t l p tr l um ed t m ke t h l l t l m l fie lf tes n l t g l t d i bl e r l hyd o n d t w k th t d t rgent d t rmed r f th h m al nd t The r w mate i l a l d l b t e tak n la g ly f om th h f t f th d l

p t a t le n the m mp rt t p d t S / L PE LT A P S H L ITE GAS- O SE L R A T PETRO E t P TR LE T P C r NG [so]

Petroleum reservoir engineering

Th rpl d n n d w th the dev l p m t d p t f rvo f ma im m ec n m f l g r t th lt m po t t h l g q i g d n t d appl t n f m p) t h d ipl n uch phy geol gy l m try a d rt th m t a ll tt g z i n th t d of il mpl rs s t m

The g mea re (a r er ir a an entity of mmer ial nter t a e (1) the am unt f o l ga or b th i tally pre ent in the re ervoir (2) the r te t wl i h th hydro arbon can l witldra a d (3) the fraction f th original hydr carb n in pl c whi h can be e omically reco ered

Oil or gas in place The am unt i itially in pla e an b dete mined imply a the l m f r erv r o k e nt n ng the h dr carl f in te e t time the content per unit v l im of rock Th f rm r an be ol ta ne l by the tl ck e f the producti format on at well d ill d for it d vel pment and the tot l pr ducti e rea def ed and outlined l y the well The il r gas c nt nt per unit v lume of o k s e tually given l y tl m a ured r alc ilated p ity r duced l v th am nt of w t r atur t n from the r rv ir vol me f the hydro arl n il volume t the ur fac an b al ulated Tl twc volum d ffer l e cau e f hr nkag of rude o l on e oluti n of it l t on g or xpan i n f fre re ervo r ga a pre e de l n t atm pheric The f rma t n thickn p r ity a d c nn t r int r titial water t ration h ld l e con id r d a l e lly va iable to tl xte t that su l ari t n can l e d t rmined fr m inf mat n btained at th in di id al w ll

If tl t tal mea ur d o l b aring or pr d ictive area n a r i t d cated by A tl e rage f m t th kne s of th prod ct n x luding n npr ducti e m mber u h a sh le n f et by h the a e age p ro ity by φ th a rage w ter at at o by S nd the f mat n l m fact r of the l by B th niti l rfa e (tock tank) oil content in plac N will b g n by the equat n

$$N = 7\,758Ah\varphi(1 - S\ )\ B \quad \text{barrel} \qquad (1)$$

F the gas cap of n l ng o l re rio a non iated g rs the g onte t woul l b dete m ned by the me qu tio pr vide l the te m B i repla d by B the ol me at e r ir nd ti f a unit v l ime of g s at th u fa e The ga ntent n ub f et obta n d by mult pl ng th alc lated olume i ba r l by th f ct 5 614(F r a com e ec nt g f the ga o te t that d ol d n the il (th olition ga) i al ular d a th il ont nt t mes the g l b l ty t the n t l nd tio exp e d ul f tp b r l

The material balance equation Th in t al l pla ca l b i fe r d f m b rvat th p ur beh w th n the re rv i a o l and g p od c d Maki g a m t rial b lance f the ga a d il by nter l t ng th lum s pr du d with the am unt a umed to be i it lly p e nt t f und th t N ll b gi e by the n t ri l b l c quat n

$$N = \frac{N\left(\dfrac{R - R + B}{B}\right) - G - \left(\dfrac{1}{B} - \dfrac{1}{B}\right)G - \dfrac{W}{B}}{R \quad R - (B \ - B)/B} \qquad (2)$$

where G = initial reservoir volume of free gas phase present
W = net water intrusion volume
N_p = cumulative oil production
R_p = cumulative gas oil ratio (total gas produced divided by N_p)
R = gas solubility in oil
G = cumulative gas injection if any subscript i elsewhere indicates initial values

In this equation N and G are the basic unknown constants N_p R_p and G are the actual quantities of production or injection and R B and B_g as well as their initial values are functions of the pressure and can be determined by experiments with the oil and gas W is in principle a variable unknown

If it is known that the water intrusion term is not of an important magnitude and can be neglected the material balance equation reduces to one with the two constant unknowns N and G Application of the equation to two or more time periods for which the other terms are known will then permit its solution for N and G

If G may be taken as zero but the water intrusion term W is not an insignificant factor calculations of N on ignoring W will show an increasing trend as production continues This in itself will be strong evidence that water encroachment is playing a role in the pressure performance Extrapolation of the calculated values of N to the time of initial production will often indicate reasonable values of the true magnitude of N Conversely if the latter is known or can be estimated independently the material balance equation can be inverted to calculate the volumes of water encroachment corresponding to the production performance

Darcy s law permeability The rates at which the hydrocarbon fluids can be withdrawn from a reservoir depend on the number of wells draining the reservoir the average thickness of the formation and the inherent transmissibility of the reservoir rock for these fluids The last factor is expressed by the term permeability Its significance lies in that it is the coefficient of proportionality in the basic physical law governing the flow of fluids through porous material namely Darcy s law (*see* FLUID FLOW PRINCIPLES) In its generalized form applicable to flow in a direction s inclined to the horizontal by the angle θ it may be expressed as

$$u = -\frac{k}{\mu}\left(\frac{\partial p}{\partial s} + \rho g \sin\theta\right) \tag{3}$$

where u is the volumetric rate of flow per unit area μ the fluid viscosity ρ the fluid density g the acceleration of gravity $\partial p/\partial s$ the pressure gradient and k the permeability If u is expressed in cc/sec μ in centipoise $\partial p/\partial s$ in atmospheres/cm and ρg in atmospheres/cm then k is in darcys

The permeability unit darcy may be defined as the permeability of a porous medium which will carry a flow of 1 ml/(sec) (cm) of a 1 centipoise (cp) viscosity fluid under a pressure or hydraulic gradient of 1 atmosphere/cm

In most practical applications it is convenient to express the actual permeability in the unit of the millidarcy or thousandth of a darcy (md) Consolidated producing sands generally have permeabilities in the range of a few to several hundred millidarcys The permeabilities of unconsolidated sands and fractured or highly vugular limestones often range in the thousands of millidarcys Tight productive limestones frequently have matrix permeabilities even lower than 1 md

In the above differential forms of Darcy s law the permeability k is to be considered as being variable from point to point in the medium if the latter is not uniform throughout even though the fluid itself persists as a single phase liquid or gas It may also have different values for different directions of flow The primary variable is the pressure p The validity of Darcy s law has been established by extensive experimentation although as most linear relationships do it tends to break down if the fluid velocities are indefinitely increased Within such limits which encompass virtually all situations of practical importance the flow is considered to be viscous

The permeability defined above is independent of the nature of the fluid provided it occupies the whole of the pore space and depends only on the character of the porous medium The viscosity and density alone suffice to discriminate between one fluid and another At low pressures however permeabilities measured for gas flow have been found by L J Klinkenberg to be higher than those determined for liquid flow but this effect is of minor importance except in laboratory experimentation on low permeability material

Perhaps the simplest application of Darcy s law to a problem simulating one of actual oil and gas production relates to the steady state horizontal flow into a well bore Assuming the flow is radially symmetrical about the well it is readily found that the pressure will increase as the logarithm of the distance from the center of the well The rate of liquid flow is then given by the formula

$$q = \frac{2\pi kh(p_e - p_w)}{\mu B \ln r_e/r_w} \tag{4}$$

where k is the permeability h the formation thickness p_w the pressure at the well of radius r_w p_e the external pressure at radius r_e μ the viscosity and B the formation volume factor of the liquid

In common practical units this equation becomes

$$q = \frac{0.00306\,kh(p_e - p_w)}{\mu B \log_{10} r_e/r_w} \text{ barrels/day} \tag{5}$$

where k is expressed in millidarcys h in feet μ in centipoises and p_e p_w in psi The external radius r_e though not precisely defined represents the radius from which the liquid is being drained or that where the pressure may be assumed to be p_e

P t l m re erv Ireng

F r s m la te dy tate rad al flow f gas nt a w ll th r te f fl w q t 60 F and 1 atm phere s f d to be g by the equ t n

$$q = \frac{0\,30\text{o}6kh(p^2 - p^2)}{\mu ZT \text{ l } g \text{ } r /} \text{ ft /d y} \qquad (6)$$

wher Z r pr t the a age upe comp es ib l ty d i t o f t r of the ga n th e rv i s comp ed t n d l ga a d T the reservoir temp r t e i ░ (R nk ne)

Mult phase pr d t o Act l sy t ms alway n l em tha flu d ph e G nd o l d w t r a d l ░ the m t c mm fl w tream mb l But whe g s a d o l a ░ flow g d d ally ngl ph s th p e-en e of th imm ble c n te wate mu t b t ke nt a c t

Expe im tal tud h ░ how th t the mult ph fl w th o gh p s medi an st ll be de-bed by th b i D r y type f equat pro-ided it i appl ed t e h d t t pha e p r t ly a d th a ted p rme b l ties a n ide ed t b f ct of th flu d pha e s t r ti n I d ti g th l g a d wat pha ░ by the ub-sc pt o g nd the multane fl w in th d e t t n l θ w th the h r z tal w ll b g ed by th eq t

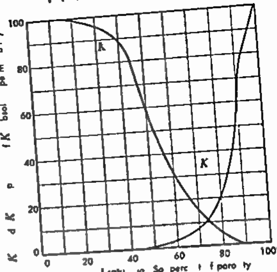
$$= -\frac{k}{\mu}\left(\frac{\partial p}{\partial} + g\rho \quad n\,\theta\right)$$

$$= -\frac{k}{\mu}\left(\frac{\partial p}{\partial} + g\rho \qquad \theta\right) \qquad (7)$$

$$= -\frac{k}{\mu_w}\left(\frac{\partial p}{\partial} + g\rho \quad s \quad \theta\right)$$

Th el t and u_w r p t th l m t fl ate f the rresp d g ph s The p ░ e xp es ed i d d ally ░ e they w ll h g d t n u ly s the rved te f b t ee th phas Th e pr u e d ff r fe ed t p lla y p e r d m y be d ed f i f th ph t r t t b m u ed exp me t lly alth gh th y d t m d d tly by th te f l rv t es d t fa l t s Th y ar fte ░ ed the t tme t f l rge-sc le y t ms ░ t th y m y b f mp t e fl d f ░ nd ░ f p d h g f th fl d s tur to

Eff i d l n p m b l t Th p m b l t e k_w k d k re t rm d ff ti pe m b l t es Wh e p e ed fr ct f the p rm b l ty f gl fl d ph th ab l te p rm b l ty th y re lled l t pe m b li t The l tt lw y le than 1 eff t g the i f f h ph e w th th fl w f th th Th t t f wh h they e f t ░ p ed the f t f the p sp e wh h th y occ py nam ly S_w S d S w th m lw y eq l t 1 Th t on f the l t p m b l t w th the ph e tu ati n i f ed t a the p rm b l ty t at l t d by F g l f r a m t



I satu io So perc t f poro ty
——— co sol d ed so d K=0.5

Fg 1 G d l l t p m b l ty rv fo a N h l B ff d t (Aft B r ! AIME T)

f g s a d l fl w ng thr ugh a Nich ls ░ ff sand st n

I nt rp et ng the e urves it i helpful t d s-t g ish betwee th gas as the no w tt ng pha e a d the o l a the wetti g ph e refe ri g t th ir especti e tenden i prefe ent ally t dh re t d w t the i ter al l d surf ce of the rock It the w ll be bserved th t the perm abil ty f the wetting pha e—oil n th ca e f Fig 1—d ops p dly s ts at r t on decre es f m 100% a d f lls t z r l ng b f e ts at ration nt hes Th s d p is d to the fact th t the it l des tu a t f th w tt g pha e i th la ge po es whi h ontrib t m re t the pe m b l ty than th r prop t l l m tr ░ nte t Co er ly t h gh r deg es of de tu ti of th wetting ph e th l tt i left in the fine t p es a d i d c nn ted fl w h n ls—the red cible at a ti —p rmutt g egl g ble fl w c pac ty

Th nw tti g ph e—gas—tend t ma n d tun ly d tr b ted t te w th ze pe m b l ty til ffi ░ t ░ t —th eq l b-m t ti — b lt p f nt ty t b t bl h d Th l g r p e ch l so up ed th p de ap dly ri g perm b lity w th n c i g ga tur t V t lly f ll gle-ph e p me b l ty h e ed at l tha mplet l qu d de t rati n d whil the malle t p e till filled w th l qu d

F the m g eral c wh e th pha s—l g and w t r—are fl w g t i f d th wh ░ th pe m ab l ty t th wett ░ ph e-w t n lly—i det rm ed ly by t wn t t n and q l t t ly f ll ws a c e h th fo ll in F g 1 the relat e p m b l ty t th r g m y d p nd o the d t b t a w ll m i f th th tw ph ses The e eff ct ll t ated Fig ░ nd 3 howi g triang l pl t th lt f d f c n l d t d

C rves f this type can i d at m ny f the gr

where G = initial reservoir volume of free gas phase present
W = net water intrusion volume
N_p = cumulative oil production
R_p = cumulative gas oil ratio (total gas produced divided by N_p)
R = gas solubility in oil
G = cumulative gas injection if any subscript i elsewhere indicates initial values

In this equation N and G are the basic unknown constants N_p R_p and G are the actual quantities of production or injection and R B and B_g as well as their initial values are functions of the pressure and can be determined by experiments with the oil and gas W is in principle a variable unknown

If it is known that the water intrusion term is not of an important magnitude and can be neglected the material balance equation reduces to one with the two constant unknowns N and G Application of the equation to two or more time periods for which the other terms are known will then permit its solution for N and G

If G may be taken as zero but the water intrusion term W is not an insignificant factor calculations of N on ignoring W will show an increasing trend as production continues This in itself will be strong evidence that water encroachment is playing a role in the pressure performance Extrapolation of the calculated values of N to the time of initial production will often indicate reasonable values of the true magnitude of N Conversely if the latter is known or can be estimated independently the material balance equation can be inverted to calculate the volumes of water encroachment corresponding to the production performance

Darcy s law permeability The rates at which the hydrocarbon fluids can be withdrawn from a reservoir depend on the number of wells draining the reservoir the average thickness of the formation and the inherent transmissibility of the reservoir rock for these fluid The last factor is expressed by the term permeability Its significance lies in that it is the coefficient of proportionality in the basic physical law governing the flow of fluids through porous materials namely Darcy s law (*see* FLUID FLOW PRINCIPLES) In its generalized form applicable to flow in a direction s inclined to the horizontal by the angle θ it may be expressed as

$$u = -\frac{k}{\mu}\left(\frac{\partial p}{\partial s} + \rho g \sin\theta\right) \qquad (3)$$

where u is the volumetric rate of flow per unit area μ the fluid viscosity ρ the fluid density g the acceleration of gravity $\partial p/\partial s$ the pressure gradient and k the permeability If u is expressed in cc/sec μ in centipoises $\partial p/\partial s$ in atmosphere /cm and ρg in atmospheres/cm then k is in darcys

The permeability unit darcy may be defined as the permeability of a porous medium which will carry a flow of 1 ml/(sec) (cm) of a 1 centipoise (cp) viscosity fluid under a pressure or hydraulic gradient of 1 atmosphere/cm

In most practical applications it is convenient to express the actual permeability in the unit of the millidarcy or thousandth of a darcy (md) Consolidated producing sand generally have permeabilities in the range of a few to several hundred millidarcys The permeabilities of unconsolidated sands and fractured or highly vugular limestone often range in the thousands of millidarcy Tight productive limestone frequently have matrix permeabilities even lower than 1 md

In the above differential forms of Darcy s law the permeability k is to be considered as being variable from point to point in the medium if the latter is not uniform throughout even though the fluid itself persists as a single phase liquid or gas It may also have different values for different directions of flow The primary variable in the pressure p The validity of Darcy s law has been established by extensive experimentation although as most linear relationships do it tends to break down if the fluid velocities are indefinitely increased Within such limits which encompass virtually all situations of practical importance the flow is considered to be viscous

The permeability defined above is independent of the nature of the fluid provided it occupies the whole of the pore space and depend only on the character of the porous medium The viscosity and density alone suffice to discriminate between one fluid and another At low pressures however permeabilities measured for gas flow have been found by L J Klinkenberg to be higher than those determined for liquid flow but this effect is of minor importance except in laboratory experimentation on low permeability materials

Perhaps the simplest application of Darcy s law to a problem simulating one of actual oil and gas production relates to the steady state horizontal flow into a well bore Assuming the flow is radially symmetrical about the well it is readily found that the pressure will increase as the logarithm of the distance from the center of the well The rate of liquid flow is then given by the formula

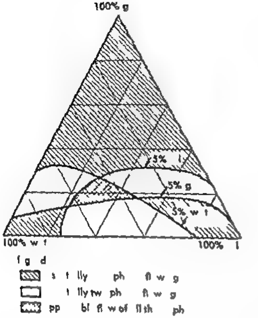
$$q = \frac{2\pi kh(p - p_w)}{\mu B \ln r / r_w} \qquad (4)$$

where k is the permeability h the formation thickness p_w the pressure at the well of radius r_w p the external pressure at radius r μ the viscosity and B the formation volume factor of the liquid

In common practical units this equation becomes

$$q = \frac{0\ 0030 \ 76kh(p - p\ )}{\mu B \log\ o\ \ / w} \ \text{barrel /day} \qquad (5)$$

where k is expressed in millidarcy h in feet μ in centipoises and p p_w in p i The external radius r though not precisely defined represent the area from which the liquid is being drained or that where the pressure may be assumed t



Fg 4 C mpo t d t b t f th ee-ph fl w t m o old t d d f t s f th fl d t t (Aft L tt d L w AIME T)

pl m t A pre r ed t on n s h gh as 3000 p i w ll l d t an exp n f tle wat r f nl abo t l[c]

R o r d ha e c mp e sibilit of the rd r f 15 × 10 per p d p r q n (ps) o b it fi e tim a gre t s w te Hen f the rv i l d tur ted by e l tho a d p t mp nergy lo e nav p o de an xp n t lume and di pl em t t th pr duc g w ll f a f w re e t f the total ol m f th l in pl O ca i lly l e r i th ra g may be f e m c al e U ally h we th e p n on d pls nt of d t r ted o l nly a uppl ment t p oduc t nt oll d b ther m h m

W r dr s t s The omp on ergy f th wate i aqu fer wh h adjo d a n mmu at th o l s rv ft n th d m n nt ne gy ur e a d m ha m fo l e y Thes e the wate dri rv r Th mp rtant h e te t ti a th l met c xte t d the nt u t f th a ju f a d its en gh t pu l th l t t mm ally p fit bl ate

T th e t nt that the aq fe m y lt mately t n tle l h ghe th n the o l e rvoi the f d g h dr l c h ad w ld in pr nc pl p d a tes d e f d pl c ng the l fle f th l ng fl w p th h wev r th t f fl w th gh th qu f h le will us lly he too l w t x t n app [illegible] nfi e on th es rs odu t O the th r h d st th rv la m f m f w t r n xt nd d aq fer wh h m ke th r omp i e rgy and exp n p t t l mport t f ct s il d place-

ment A circular 50-ft tl ick aquifer f 50 mile eq i alent ra lius will contain enough water to xpand s me 1 500 000 l bl f r each p i of p e st re red ti n Such le els of volumetric e pan ion co ld well support and repla e the oil withdrawals fr m a g eat majority of il pr ducing re ervoirs If the adjo ing a uifer i of mo e l mited extent r its large ale cont nu ty i interrupted l y fault n or l thol g c barri r it contril ution will be cor e p dingly l mited

A major pha e of th tudy of a water drive r ervo r is tl pre ure and flow l eha i of the aqu fer it elf If the water compr il l ty and uch c tribi tory effects fr m the r ck a may occ ir i taken a a n t nt c tl e water den ty in the aq ife will b g er d by an eqi ati n identical w th th l s ical he t c nducti n equation namely

$$\eta \nabla^2 \rho = \frac{\partial \rho}{\partial t} \qquad \eta = k/\varphi c\mu \tag{9}$$

To a ery clo e approx mat on ρ can be replaced di e tly by the pre u e p

Solut ns of the abo e equat ons analyt cally by l ctri l netw rk m del or by d gital mputers w ll how h w the pr e in the aquifer will re ct t fluid withdr w l wh h n t n can b related to the il and gas produ t on in the adj i t g o l e ervo r the rat f water n a on into th latter Con e ly f m b r ed or a umed pres- ur h tor at the wat r oil l u d ry the rate of fl w a ro th b und ry nd int th il re ervoir c n be alc l ted The geom t cal and phy i al p pert es f the aq fe ab ut wh l ad ance i form ti e s ften me g an b d te m ned in an empi ic l n e by t al and rror adj tments so a t make the pred cted pr ur l hav m tch th t b rv d n the our l pr du in the il e rv ir

Ma y tud es of th type nd f eld h er ations how that the p ss re in water-d i reservoirs is ate se iti e That i the a e age re rvoir p es e d pends not only the imul t v oil pro- ducti n l ut als on the rat at which it has be n w thdrawn Sh rp in rea fl ducti r te w ll tend t ele at th pre u d li e pe un t w thd awal Cuth ks in w thdr wal rat will gen e ally t rd tl pr e decl ne nd ft n e en l ad to b ild ps i res rvo r pre u e

Wat r dr ve e erv w ll pe m t ma nte ance of high rates f tot l fluid withd awal th ugh mo t of th e on m l fe although incr a ing vol m f wate pr d cti n w ll c nt n ally ed e the n t o l r tes The re erv i p re will te d to tab l ze afte niti l decl ne whi h a e nece sa y t duc th w ter t flow int the il zone at o l ll s ll nly mode ately du i g the pr d ing l fe and n r l t n t th decli e in e ert i p u

Th wat d m h n m f pe r l impo t n e be us of th high o l eco eries t often y lds Re o y f t s h gh a 50[c] of th it al l i pl e a e not unc mmon a d und ry fa abl d t n they ay be a h gh a

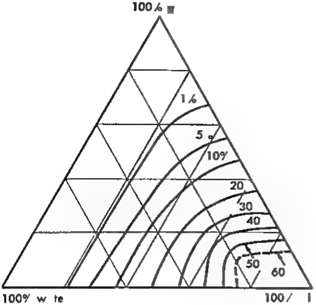


Fig. 2. Curves of constant oil relative permeability in flow of oil, gas, and water through an unconsolidated sand as functions of the fluid saturations. (After Leverett and Lewis, AIME Trans.)

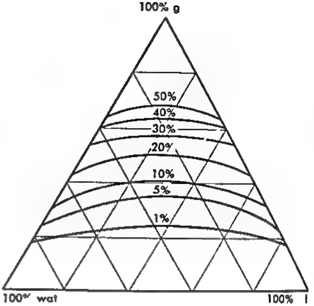


Fig. 3. Curves of constant gas relative permeability in flow of oil, gas, and water through an unconsolidated sand as functions of the fluid saturations. (After Leverett and Lewis, AIME Trans.)

features of multiphase fluid flow in the porous medium of interest. For example, the nature of composite flow streams which can be maintained in different saturation ranges is illustrated in Fig. 4. It will be seen that simultaneous flow of all three phases in significant amounts will occur only in a very limited range of fluid saturations. By further reference to Figs. 1, 2, and 3 it will be observed that the composite permeability in multiphase flow will generally be but a nominal fraction of that for single-phase flow.

Computing components of flow. The actual fraction of any composite flow stream contributed by a particular phase can be calculated by combining the corresponding Darcy equations. For example, when gas and oil are flowing simultaneously, the fraction f_g of the total volumetric flux q represented by the free gas phase is given by

$$f_g = \frac{\lambda_g}{\lambda_o + \lambda_g}\left[1 - \frac{\lambda_o}{q}\left\{\frac{\partial P_c}{\partial s} - (\rho_o - \rho_g)g \sin\theta\right\}\right] \tag{8}$$

where the terms λ_o, λ_g are the oil and gas phase mobilities, that is, the ratio of their permeabilities—the effective values—to their viscosities; P_c is the capillary pressure $p_g - p_o$. The corresponding fraction f_o of the oil phase f_o is simply $1 - f_g$. For oil-water flow streams the oil and water fractions are given by the same equation after appropriate changes in the subscripts.

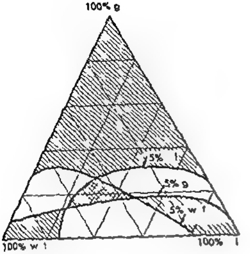
Relative and effective permeabilities are of importance not only in determining the detailed dynamics of the displacement of oil from reservoir rocks but also control the absolute flow rate. In the above equations for rates of production from wells the permeabilities must be corrected for the connate water even if it is in its irreducible state and immobile, although the steady-state single-phase flow equations will give only approximations of the actual flow magnitudes if both gas and oil are being produced.

Energy and producing mechanisms. Two basic though elementary observations underlie the essential principles of reservoir engineering. The first is that movement of viscous fluids such as oil through a reservoir rock involves the consumption of energy. Secondly, the withdrawal of oil from an oil reservoir requires a replacement of its volume in the reservoir space. Considered together, these simple facts provide the framework for understanding the various types of oil-producing mechanisms.

Energy required for movement of oil from a reservoir rock into the producing wells may be drawn from four sources: (1) reservoir rock compression, (2) compression of reservoir and surrounding liquids, (3) compression of solution and free gas, and (4) gravity head at the levels of withdrawals. Their individual importance depends not only upon the amount of such energy available but also on the effectiveness with which it can be used to displace the oil.

Upon release of the fluid pressure within the pores of a reservoir rock with removal of the oil and gas, the rock matrix will be subjected to increased compressive stress and compaction of the rock mass. However, in consolidated rocks the magnitude of such compaction within the reservoir itself will usually be too small to play a significant role in the oil expulsion process. Observable and serious compaction has indeed actually occurred in a few unconsolidated sand reservoirs, but in most cases the competence of the overburden apparently makes the compaction effect of minor importance.

The expansion of the connate water within a reservoir, assuming the water is under pressure, will also generally be a min



l g nd
lly ph fl w g
t llytw pha fl w g
pp bl flow of lll th ph

Fg 4 C mp ti d t b t f th pha fl w t m n ld t d d fu t of th fl d s tu t (Aft L tt d L w *AIME* T)

pl ment A pr ure d ti n eve a high a 3000 p w ll le d to n expa on f the water of nl ab t 1%

R tv ude h mp s l lt f tle de f 15 × 10⁻ pe po nd p r q n (p) ab t fi e time a g eat s w te Hence f the es rs l, nder atu t d bv e l th u nd f i mpe i n ene gy l e m pr id e p n tu t lum d d pl c ment t th p d g lls f a f w p nt f the tot l l m f th l pl O a io allv o l re- es th ng m y b of e om) e G lly m er th p n s di placeme t f nd m ated l only a uppl m t to p d e f nt lfed by th m h i m

W r d Th mp s n e gy f th w te n qu fe wh h adj n d mmu cat w th l rvo rs ften the d m n t n gy n nd me h n m f r l o r Th e r th water dri e rv Th mport t h act t c ar th lum tr c xt t d th nt u ty f th aq f r nd ts l l t t b g t i to th oil r o f st n gh t p h the l t t mme i lly p fit ll r te

T th t th t th aq f rs m y ult m t ly ut r p t l el t gh r th n th l e rs i th rrespo d g h d l h ad w ld n pr pl p d m d e f d *pl g th il* Bec of th long fl w path h wes th rates f fl w th ugh the qu f wh le w ll u lly be too l w t e t ppre able flu nce n th t rv prod ti n On the th r ha d t th v y l z l m f w t r y *e r nd d qu fe s* wh h m k th mpr n rgy a d p pot ntial imp rt nt f ct rs o l d pla

ment A ci cular 50-ft th ck a q ifer of 50 miles equ valent radius will co tain eno gh water to pand me 1 500 000 bbl for each p of pre ure reducti S ch lev l of v lumetric expa i n could well upport a d replace the il w thdrawals from a g e t majo ity f il produ ing re ervo r If the adjo ning aquifer i f m re lim it d extent r its large- cale c nt nu ty i interr ipted f y fault ing r l thol g c barri r its contrib t on will be c rre pond ngly limited

A major pha e of the st dy of a water dri e re ervoir i th pre re and fl w l ha i r f the aquife it elf If the water mpre ibility a d such cont ibut rv effects fr m the rock a may occur is taken s a on tant the water den ity in the aq ifer will be go rned by an equat o identical w th the cla ical heat conduct on equ tio n mely

$$\eta \nabla^2 p = \frac{\partial p}{\partial t} \qquad \eta = k/\varphi c\mu \tag{9}$$

To ery clo e app ox mation ρ can be replaced di e tly by th pre su e p

Sol t s of the abo e quations analytically by el ctr cal n two k model r l y d gital computers w ll show h w th p r e n th aq if r will rea t to flu d withdraw l whi h i t rn can be related t the il a d g s pr d cti n n the adjo n ng il ervo r the rate of water in si n i to the l tter C nver ely fr m b erved or a um d pres- s r h t ries t the water il b unda y the rates of fl w a s the b unda y and nt the oil r erv ir c n be calculated The geometri al and phy cal p op rt es of the aquif about wh h ad ance nf mat n is often meage e n l e determi d in n emp ic l by trial and er o adju tm nt o as to make the p di ted pre u beha ior mat h that b erved in th c u e f produc ng the l e erv r

Ma y tud f th s typ and fi ld b ervati ns show that the pres w ter dr ve e erv rs is te e m e That i th a er e erv i pre s re d p nd t nly on the c m latı e o l pro- duct n but al n th rate t wh h it l a been w thdrawn Sl a p n r e in produ t on *te will* t d t c eler te th pr e decl *e p r unit* w thdrawal Cutba ks in withdrawal r te w ll gen er lly ret rd the pre e de l e and ften en l ad t bu ld p n res rvoir pr u

W te d i a rvo s will perm t maint nance of *h gh r t s of t tal fl d* withd aw ls th o gh m t of th c nomic l f alth gh inc eas ng ol ume f wate prod t n will onti u lly r d th net l r tes The r rvoi p e su e w ll t nd to t b l e ft r t iti l de lines wh ch nece ary to du e th wate to flow i to the l z ne at t nt at to place the l w thd awals Gas- il t s will r e only m der t ly du ng the p duc g lif and l t n t the decli n rvo es ure

Th wat r dr e r echa m s of p c al imp r tan becau e of the h h o l r c ve i t fte yi lds R ery fact s h gh 50% of th in tial l m pl e a n t u mmon nd nde v ry fa or ble c nditi n they may b s high a

80%. The main factors controlling the recovery are the uniformity of the oil reservoir body and the viscosity of the reservoir crude. Variations of the permeability in the producing formation may lead to channeling of the invading water through high permeability zones and premature drowning out of the producing wells, so that while the oil displacement efficiency may be high in the invaded strata, the over-all average sweep efficiency and recovery will be relatively low. The viscosity of the reservoir crude controls the local displacement efficiency. The latter will be reduced as the oil viscosity increases. Because of this factor water-drive recoveries in reservoirs producing oils of gravity lower than about 20 degrees API may be considerably less than the 50% frequently observed for high-gravity producing reservoirs.

The water-drive producing mechanism controls the production in important reservoirs in all major oil provinces. Many of the large reservoirs in Texas along the Gulf Coast operate under water drives, as does the East Texas Field, the largest in the country. The two main sands in the gigantic Burgan Field in Kuwait are virtually perfect water-drive reservoirs.

Solution-gas drives. The gas dissolved in reservoir crudes is the most common energy source and displacement medium involved in oil production. When it is the dominant agent for oil recovery the producing mechanism is termed the solution-gas-drive or depletion drive. The decline in reservoir pressure which necessarily follows any appreciable production of oil and gas will lead to liberation of solution gas within the pores of the rock and corresponding replacement of the volume of reservoir fluid withdrawn if the oil is gas-saturated at the initial pressure, as it usually is. If the adjoining aquifer does not then supply an influx of water to provide for continued replacement of the oil withdrawals, the pressure will keep on falling, with continued additional evolution of dissolved gas. Ultimately the pressure and the dissolved gas will be dissipated and the economic life of the reservoir will be terminated.

The reservoir pressures and displacement processes in dissolved-gas-drive systems basically are not rate-sensitive. They depend only on the reservoir volume of total fluid withdrawals, although the rate and manner of oil production may affect the relative amounts of gas and oil produced and hence the total composite voidage for fixed quantities of oil recovery. As the evolved gas builds up the gas saturation the permeability to the gas will grow, facilitating its escape to the producing well without a corresponding increased displacement of the reservoir oil. As a result, after an initial period of rather constant gas-oil ratios at the level of the initial solution value, the ratio will rise steadily to peaks of the order of 10–20 times as great and then decline as the contribution of the free gas falls with decreasing pressure. The well and field producing capacities will also fall because the driving reservoir pressure drops and the permeability to the oil is reduced with increasing gas saturation.

Except for local effects about the producing wells themselves, the over-all history of depletion of a gas-drive reservoir can be predicted by the equation

$$\frac{dS}{dp} = \frac{\alpha S + (1 - S - S_w)\epsilon + \zeta S(\kappa - rR/\gamma)}{1 + \frac{\mu}{\mu_g}(\kappa - rR/\gamma)} \tag{10}$$

where $\alpha = \frac{B}{B}\frac{dR}{dp}$, $\epsilon = \frac{-1}{B_g^2}\frac{dB_g}{dp}$, $\zeta = \frac{\mu}{\mu B}\frac{dB}{dp}$

and $\gamma = \frac{\mu B}{\mu_g B_g}$, $\kappa = \frac{k}{k}$

r is the fraction, if any, of the produced gas which is returned to the reservoir. R, the current gas-oil ratio, can be related to the other variables as

$$R = R + \gamma\kappa \tag{11}$$

In these equations α, ϵ, ζ, γ, and μ are all functions of the pressure p determined by the properties of the gas and oil. The pertinent rock characteristics enter through κ, the ratio of the gas to oil permeability, as expressed as a function of S. The solution of Eq. (10) will show how the current oil saturation S in the reservoir declines with falling pressure. It will also give the gas-oil ratio R at the corresponding period. The associated total oil recoveries per acre-foot of productive reservoir at any stage of depletion will be found by

$$N_p = 7758.4\varphi\left(\frac{S_{oi}}{B} - \frac{S}{B}\right) \tag{12}$$

Solutions of Eq. (10) give the typical performance relationship of reservoir pressure and gas-oil ratio versus cumulative production as is observed in actual producing fields. By its construction, in which local well-bore effects are ignored, it does not provide for any rate sensitivity of the recoveries.

Except for the mechanism of undersaturated reservoir oil expansion, solution-gas drives are the most inefficient producing systems. This is not because of the lack of sufficient solution-gas energy but rather because of the internal bypassing of the gas as its saturation is built up, so as to escape from the reservoir at high gas-oil ratios and little displacement effectiveness. The increasing oil viscosity as the pressure declines and the shrinkage of the oil upon gas release aggravate this effect. Ultimate solution-gas-drive recoveries are 10–30+% of the initial oil in place, decreasing generally as the API gravity decreases or as the oil viscosity increases.

Solution-gas-drive recovery has been the dominant producing mechanism in many of the older fields developed in the United States in the mid-continent area, West Texas, and California. In recent years appreciation of the low recovery efficiency of this drive has led to the [illegible] of fluid-injection operations or limitation of the rates of production so as to facilitate potential water-drive or gravity-segregation as more efficient recovery mechanisms.

C ty d inage dri e G s aps l ing an l e c tan addit n l comp o en gy f l d pla em nt t s pplem t that of olut on g (ee PETROLEU t GEOLOGY) If a may l ppen u d h gh pr ducti n r t and p es ir d fferen tal th s gas is pe m tted to br k nto th oil z ne and) the l tion ga fl w tream t will be di pated ap dly and w ll re ult i rath r l m t d i r ed l e o erie Its effe t will be m i r t that f d per d ga nj ct n di ectly t th l If h e e the pre r grad ent n th re erv re r str ted a n t t over b l th g a itv d ff t al betw e th gas and o l th ga c p w ll b pre e ed a a eg egated d g pi t n the l z n

S mpl d wnw d dr nage by gr v ty f l m a rt l e l mn f p r m d um w ll lead to l w r du l l atur t a d h gh overies l m t d niv b the p rm ab lity w ttab lity and ap lla y p u e cha a t r t c f t le r ck In a t f ern r with r with t ga c ps it i g lly n t f a ble to imulate p re gr ity d a ig b a the c r e po ding rates of pr du t o w ll be t l w for m x mum e onom r t rn Th he t d wnwa d flow apa ity of the k w ll b fu the e t ct d by th dec e sing p m ab lit t l th p u e d l ne and th l t ga es l d

I p a t wh th ppe part f e rv r t p nta n g s p th mp n ene gy of th gas t perm tt d t p l m t that of the g ty he d a t p de at f withd aw) at n m l l The ga ap al o erv as a u ge h mh t r t d th pre r d h and hen e le n th ate f g l t n w thi th o l z ne d th a ted ffe t l d ed l p m ab l tv nd d l ity

The d pl c m t ll ti ne of th e pa di n th u d lvi l z n d d dl r t t m y b nf rred fr m E (8) Th gr t dr m h i m a whole l kew se ff t d b th t t d pl c ment p oces es d b m l effi ent a th l tte ner a e To f th h gh y p t t l f th gravity d g m ha m n s c p e rs bal a m t l mad b twee the ben fi tal u e f th d g p r th g cap t pp t the des ed l l f d wnfl nk p d t on nd the m it d t r or i n th d pla eme t effi wh th h in d d th l o e Wh t a bal e h ed th g s p will pp t pa d d n d a p t n w th a l t l h p g l ta t t n ll d f bl e t on f gr ty-d a ag pe t the pwa d b n y f c n th ga l e th th ll m th d wn fla k p g d t nd the g w ll m g at p t t t th g p wh l th l g d w d S b o nt a r nt g s m gr i n will i n m t g th t r pr a whole a w ll a h gh l l f l t at n nd pe m l lty in th l n F n h the e o t l g p l p oc n l d t th f rm l f p w th b q t b

ha i r e ent ally imilar t that of a primary gas cap

The pres ure in gravity dra nage dri es in which eff cti e gregati n betwe n the ga and o l ach e ed will decl ne lowly Production rates and apa ity will hold rath r teady except that up tr cture wells will be uc e ely h t in a the r pr du ing level are reach d by the e panding gas cap The ga oil rati s w ll follow the trend of the l t rat if downw rd ga coning i not per mitt d nd the e olved lution gas is allowe t m grat into the gas ap

T prom te the general benefits f ma nte ance f pre u e a d products n cap city pa t or all of the ga pr d ced n gra ity dra nage re rvoir ften returned to the re ervo r thr ugh injection wells c mpleted in the ga cap If en ugh njected t r pla the re erv ir withdrawals fully a d pre ent any p e ure decline th maximum p te t al f gra ity d a nage an l e a h ev d p vided it i not null fied by ex e i production rates and ga breakth ou h In any ca th higher pre s re le els wh ch the re rvoir i depleted w ll m a that wh te re idual re erv r oil do rema n und pl e d will ha e higher hr nkag and w ll repr t le n ec v red stock tank o l than if th p e u had n t been maint ined

It p eferabl that th gra ity dra nag mecha a m wh r pot t ll av l ble be allowed to f ti n the ugh ut a e ervoi s prod cing life But e when this i not fe ible g a ty drainag m y till erv t pr l ng the e onom c lif by r t rat ng th l w r part of the oil zone ft r it ap d deplet ty luti n ga d i The l n per i t ng settled p d ct n of old field wh ch h l t the r p es ur and eservo r gas fte fl t th em rgen of a ity dra nage as a es dual ur e f ne gy f r b ing ng th oil nto th w ll b r

Th m i q ement for the effect ve de elop m nt f th g ty-d a n ge mech ni m are high t ucta al rel f long o l c lumn a d good t al p me bil ty o m b l ty When the e are p e nt a d f ll ad a i ge t tak f them re e a h gh as 70-80% of the or g al o l con t t c be a hieved P p rt nately lower re c es w ll be btai d wh n gr vity d i age m ely pplem ts the luti n gas-d e m cha n m

G it dra g olte a ued by g s inj ti n at th t tur l c t h s play d n espec ally im p ta t ol th pr duction f man of the oil r n E t n Venez l A mbe of l rge fi ld n We t T a and in th Gulf C a t ha l fit d f m g a ity d a nag Se ral f th maj field lra al app to perate with g f nt gr ty g g i on

***Reservoir* engineering analysis** Th p m ry t rt g po nt f the nalys i r prediction of the p f man e of n o l eserv is its geological t u tu e nd n onme t Th s i f rmati n an o ly b at sfa t ly obta n d fr m well d illed w th the a al nfi e f th e rv o it m med i ty Ge l g l electrical d adio-

a tive logs and the study of cores of the productive rock itself provide the basic data These plu determination of the properties of the oil and gas may suffice to determine the total initial oil and gas contents of the re ervoir by applying volumetric Eq (1)

The real re ervoir ecrets unfold after the re er voir i placed on production and ob ervations are made on its performance—the history of its pro duction of oil gas and water of its pre sure and the di tribi tion of these among the variou produc ing well These data combined through the ma rial balanc Eq (2) may give further check on the initial fluid contents as well as indications of the relative roles being played by the various pro ducing mechanisms

Quite often at least two or all major types of producing mechanism will contribute appreciably to the composite re ervoir behavior and its analy is will require etting up equations for combination drive Partial water drives actually occur more frequently than complete water drive As previ ously indicated gravity drainage usually supple ments the solution gas drive proce at lea t to om ext nt Even in water drives gravity egrega tion may l e of benefit in minimizing channeling and water coning effects and thus impro ing the over all sweep efficiency

The ultimate recoverie are determined by the magnitude of the average residual oil aturation when production terminated

Recent developments Injection of gas or water to upplement the native energy and oil displace ment potential of th reservoir in its original tate have become tabli hed practice Such fluid in jection operations are now generally undertaken early in the producing life of the re ervoir and as oon as it i determined that otherwi e the re c erie will l e limited to the inefficient levels of olution gas drive or re ervoir liquid expan ion For the older field which were sub tantially de pleted l efore the de irability of pressure mainte nance was appreciated econdary rec very in tal lation have often been made in the form of gas repre uring or water flooding

The ultimate limitation of oil recovery l y pre ently tabli hed m thods lies in the fact that the fl uds—ga r water—which erve as tl e di placing pha e are l a ically immi cil le with the oil Their rface of contact are therefc re well defined inter fa es Because of the tr mendou interfacial area thu di tributed thr ughout the micro copic pores of tl e reser oir rock the e repre nt corre pond ingly large total capillary force and energies Except for their beneficial acti n in inducing im l il ition of water in water wet y tem the e capil lar force ffer re i tance to multiphase flow at all aturati n and tend to break up any flowing pha e into a di continuou and imm l ile di tril u tion a oon aturation falls to crit cal l mit When the latter tate i reacl ed the cap llary f r e hold tl e re idual oil unre overal le in pite of c ntinued pa age of immi cil le d plac ng

fluids such as gas or water The e interaction are empirically expressed by the relative permeability saturation relation hip

If the oil were displaced by a mi cible fluid the interfacial and capillary force would be elimi nated and local displacement efficiencies approach ing 100% would result This principle has long been applied in cycling gas condensat re ervoirs Here dry liquid tripped gas i injected into the formation to di place the conden ate containin re ervoir gas and at the same time prevent decline in pressure and retrograde conden ation and lo of its liquid content Both gases are mutually mis cible and the displacement proceeds ithout inter face formation and capillary force

In the ca e of an oil re ervoir di placement by a miscible liquid such as the liquefied petroleum ga es—propane and butane—would achieve imi lar results Hov er to circumvent the economi burden of refilling the whole oil re ervoir ith the e alable liquid product only a relatively mall buffer zone or slug of the latter is u ed—up to 10% of hydrocarbon pore volume—and it in turn i displaced by gas At pres ure of the order of 1500 psi or greater natural gas will al be mi cible with the intermediate hydrocarl on or liquefied petroleum gase at reservoir temperature Thu a continuous pha e tran ition is devel ped withcut tl e interface and capillary force from the er voir oil to the miscible slug and to the final ga displacement pha e Field te ts of thi method of oil displacement and related modification are n underway

A quite different type of technique for improving oil rec ve y i that of in itu coml u tion Though ugge ted many year ago it ha been tudied and de eloped on the ba is of modern re ervoir en gin ering p inc ple only e ently It appears to have special promi e in application to hea y oil re ervoirs where becau e of high re ervoir oil vi co ity and very unfa orable m bility rati s for di placement l y ga or water the latter on enti nal recovery method are of low nd often none m mer ial eff cien y

In e ence in itu combu ti n a inve tigated and te ted t date on i t of tl e inj ti n l air into the prodi ing f rmati n to i tain l urning f the oil in pla e—at temperati re of th rder of 600 F—and pr ide a fl w of l eat al ead of the coml u ti n zcn t l w r th il i t anl in crea e the reco ery anl p l ing well p d ic ti ity Tl e l irning f il il gen rat n l ti product and vaporized il ga Tl e t g tl er with the l ank of conden e l wat r ap l n a compo ite ga and water drive m ing t w rd tl e produ ing well with the ml i ti n f nt In dd ti n il g arr l eat a l rai e the t n peratur f the r ck and fl ii l ol a l f tl m bu tion fr nt alth ugh th rapid tten ti n f tl te np rature wa tend to del y tl p r ment in well p r d cti ity until th f re l t tl e p r du ing w ll Th ap r t i p r immediat ly ah a l f tl e l rn ng fr nt l l

po t f h avy l re du l r ke d the rs a f l fo th fi l ombu t on r a t o As a result th r ck th u h wh h the fi e p s left lt th r ck th u h wh h the fi e p s left e e t lly l an with ll t ld plac d r b rn d o t Abo t 15% f the i l il may b n m d n th ma er ome 85% thu be ng in p i iple r c r bl n the r k tra e ed by the fir a e the hea i mpon nt f th il e u ed f l th r i te dency f r imp o em nt i the g ty f th l r co e ed by n t m but

The fi e m y be t rted by he t s r he t n proc e d l ped je t o w lls by p n ta eou mb t n of the r rv r crud e ult ng fr m th x th rm o d t d b rpt f th yge n th i t e m Th pe at a e c rr ed n i patt r d t buti n f i j ct on d p odu g well m lar to th u ed n w t r flood g

Comme l c s f i t c mb t n re q e r l t ly h h p ty nd l t r t on a t h ld the rat of i i j to to o l p d c d d wn t c m c l l It s als e e ry t d l p gh g p m ab l ty th gh th f r m to t pe m t ffi t th gh fl w f a d mb t g e t t n the burn ng T mi m e the effect f he t l es t the t p a d bott m bo d g t t the re erv r bed mu t be of p- prec abl th k es As ll d pl me t p e u f m ty of the p du g ct n will f l t t a h ev hi h w p effi n y H w e th ap d d n e f the b ng f t thr gh a l m ted e by gr ty e r gat n of th nd g o by p rm b l ty h n l w ll l t th tr m f the d ct th rm l ffi t to th l m e the p d i g well wh h ld the w t th r high ty d l w m b l ty t l lat th e y l f f the e r

A mb f field t l h firmed th ba f b l t f ry g n tu omb t l rs At the S th B l d F ld n K Co t Cal f me 50% m f th 13-d g ee API l i pl the t t re w e ed w th 18 m th ft r j t n was t i d

Th mp m nt l cov ry p o d d h p t ly th m j r d l pm t wh h al dy ppe t h e me g fec m f b l ty It t b e p t d th t t ly ll th d the ld m th d b m t ll mp ed b t ed h b t th t t ll m e l a d p w f l t hn q w ll be b ght t l ght the f es rs g ee g p f ted

S OIL D G S FIELD EXPLOITATIO OIL A D T R C OIL B GAS WELLS PETROLEU D RY REC Y [R M]

B bl g ph M M k t *Th Fl u f H m g Fl d th gh P M d* 1946 M M k t *Ph l P cipl f O l P d t* 1949 S J P so *O I R rs E g n g* 2d d 1958

Petroleum secondary recovery

The pr ce of rem ng il f m its nat e re er o r by th f uppl mental e erg es after the n t ral ergi s ca ng il prod cti l a e l een d pleted Petr le m c da y rec erv n ntra t d pleted Petr le m c da y rec erv n ntra t w th p im ry r c ery wh ch i the il producti n r s lt g fr m nd g nou re erv ir ene g e Ad a c ng pri c pl s of techn logy nd c er ati demand th t n tural en rgy be upp leme t d o n after d c ry of a e erv ir theref re t day be t pract c s comb e the primary a d e ondary rec ery p r ds H we e tl e e are many re er wh h ha e be n depleted with ut ben fit f uppl me t l e er y a d n th narr w t e sec nd ry eco y appli s t the fu the de elop m nt f the ed pleted e erv i

S c d ry reco e y wa fir t p a t ced i th lder nd shallower p t l um reserv s of th Appalachi n r g on It h s i c spread t all il p d c ng reg ons of th world nd ha d ul led the p d c ng l f f m il fi ld Wh n e m bi ed with prim ry r c ery it i ppli d t d ep reserv r Whe pract ced n d pleted er r t is ge er lly l m t d by econ mic fa t rs to re e i s h llow r th n 3000 ft T t l il p od ctio i th Un ted Stat s by d ry reco ry meth ds n 1954 s omp led by the I te t t O l Compa t Comm s n w app o imat ly 480 000 000 bbl

Energy supplement and well patterns En rgy ppl m nt d by i tr d ti f e the g s o w te u de p r into the re rv ir The e f ga s mm nly k own s ga dri e r ga rep g th e of w te a w te fl d g Th jected fluid d s the il mai ng n the e r t th i ty f p od ct on well f m wh nce t an be l ft d t th rf c a d l o t ke up the p e with n the es rvo r p e sly oc pied by th l

Tw type f well nject o well and p du t well qu ed fo se o d y o ry op r t o St nd d patt r s ha e e ol d fo the a ng m nt f th e wells Lo ati g well p t t m pe m ts te e d l pme t f gi n l nd a nd n es the ma mum pe etr tion l je t d fl d t all p t f the re rv i I the ly hi t ry f da reco e y a gle nj t well w ded by a l g mber p d t n w ll Th p tt k ow s cl d e t ll u ed f r g s j cti perat An th p tt n th l e d a l e f i j ti well ff et by l e of p d t n w ll

The m t e mm w ll p tt the fi e sp Sq a etw k f j cti w ll d p d ti well i t l k th t a h i j t n well t th te f q a e c st g f f u p d t- well d e ch p d ct n w ll at the c t q are c t g f f j ti n well A th t d d p tt th n sp t wh h f jecti well lo ated at th rt f h g w th p d t w ll th t f he g B e ha g th l of j t p od t w ll the e p t patte

acre-ft and the fluid properties of the productive rock itself provide the basic data. These, plus determination of the properties of the oil and gas, may suffice to determine the total original oil and gas content of the reservoir by applying volumetric Eq. (1).

The real reservoir secrets unfold after the reservoir is placed on production and observations are made on its performance—the history of its production of oil, gas, and water, of its pressure, and the distribution of these among the various producing wells. These data combined through the material balance Eq. (2) may give further check on the initial fluid content as well as indications of the relative roles being played by the various producing mechanisms.

Quite often at least two or all major types of producing mechanism will contribute appreciably to the composite reservoir behavior, and its analysis will require setting up equations for combination drives. Partial water drives actually occur more frequently than complete water drives. As previously indicated, gravity drainage usually supplements the solution-gas-drive process, at least to some extent. Even in water drives gravity segregation may be of benefit in minimizing channeling and water coning effects and thus improving the overall sweep efficiency.

The ultimate recoveries are determined by the magnitude of the average residual oil saturation when production is terminated.

Recent developments. Injection of gas or water to supplement the native energy and oil displacement potential of the reservoir in its original state have become established practices. Such fluid injection operations are now generally undertaken early in the producing life of the reservoir and as soon as it is determined that otherwise the recoveries will be limited to the inefficient level of solution-gas drive or reservoir liquid expansion. For the older fields which were substantially depleted before the desirability of pressure maintenance was appreciated, secondary-recovery installations have often been made in the form of gas repressuring or water flooding.

The ultimate limitation of oil recovery by presently established methods lies in the fact that the fluid—gas or water—which serves as the displacing phase are basically immiscible with the oil. Their surfaces of contact are therefore well defined interfaces. Because of the tremendous interfacial area that is distributed through the microscopic pores of the reservoir rock, these represent corresponding large total capillary forces and energies. Except for the beneficial action in inducing imbibition of water into water-wet systems, these capillary forces offer resistance to multiphase flow at all saturations, and tend to break up any flowing phase into discontinuous and immobile droplets as soon as its saturation falls to critical limits. When the latter stage is reached, the capillary forces hold the residual oil unrecoverable in spite of continued passage of immiscible displacing fluid such as gas or water. These interactions are empirically expressed by the relative-permeability–saturation relationships.

If the oil were displaced by a miscible fluid, the interfacial and capillary forces would be eliminated and local displacement efficiencies approaching 100% would result. This principle has long been applied in cycling gas-condensate reservoirs. Here dry liquid-stripped gas is injected into the formation to displace the condensate-bearing reservoir gas and at the same time prevent decline in pressure and retrograde condensation and loss of liquid condensate. Both gases are mutually miscible and the displacement proceeds without interface formation and capillary forces.

In the case of an oil reservoir, displacement by a miscible liquid such as the liquefied petroleum gases—propane and butane—would achieve similar results. However, to circumvent the economic burden of refilling the whole oil reservoir with these salable liquid products, only a relatively small buffer zone or slug of the latter is used—up to 10% of hydrocarbon pore volume—and it in turn is displaced by gas. At pressures of the order of 1,000 psi or greater, natural gas will also be miscible with the intermediate hydrocarbons or liquefied petroleum gases at reservoir temperatures. Thus a continuous phase transition is developed with no interfaces and capillary forces from the reservoir oil to the miscible fluid, and to the final gas displacement phase. Field tests of this method of oil displacement and related modifications are now underway.

A quite different type of technique for improving oil recovery is that of in-situ combustion. This has been suggested many years ago but has been studied and developed on the basis of modern reservoir engineering principles only recently. It appears to have special promise in application to heavy-oil reservoirs where, because of high reservoir-oil viscosity and very unfavorable mobility ratios for displacement by gas or water, the latter conventional recovery methods are of low and often noncommercial efficiency.

In essence, in-situ combustion processes as studied and tested to date consist of the injection of air into the producing formation to sustain burning of the oil in place at temperatures of the order of 600°F—and produce a flow of heat ahead of the combustion zone that lowers the oil viscosity and increases the recovery and producing-well productivity. The burning of the lighter fractions ... product and vaporized oil gases. These, together with the bank of condensed water vapor, form a combination miscible gas and water drive moving toward the producing well with the combustion front. In addition, the gases carry heat and raise the temperature of the rock and fluid ahead of the combustion front, although the rapid attenuation of the temperature will tend to delay the improvement in well production until the fire moves close to the producing wells. The vaporization processes formed ahead of the burning zone leave a des-

inject n r te Con qu ntly tr atm nt f r rem al f ba teria w ll ften be nec ary Highly c r w t r m tal be a d d

The e i al ays the po bil ty that hem c l inte act n w ll occ r betwe n on onta ned n th nje ted water and those present in the nat e es rv water r e erv r mi er ls Inje ted w ter may al p oduc a ch ng in the t ture of e ervo r l y mate i l with a r s ltant reduction ff w e pa ity

I the ject o f ga p in p l attent n is paid t the r mo al f mate ial that m ght cond n th the re erv produce e rro e et on p r t g eq pm nt r y eld o idat on withi the re ervo r

Experimental developments Adva c n te h l gy l nti ed t eek mean f imp ving e d ry r co ry Pr n pal am ng th e eff t hs b the ttempt t em n npl t ly the ap ll y f rce that a ope at v n r ta n ng res du l o l Th n b acc mpl hed in the labo- r t y by p oce k w a mi e bl d pl ce- m nt l h ro s ts f pl i g the rs r o l by fl d th h h n w ll mi ompl t ly F r xample o m ght nj t a ol e t h but n t l e rv l had be mpl tely d l ed a d h g lt t th rl c B c u it n t o- n m l t th l g am nt of l nts e- qu d f th pr te hn q e h b ug gest d i ng lu f l e t f ll w d by wate g s the h t of the sol nt be g h th t t llm f l w th th f ll w ng wat o g as fl w th th il h h t t repl Ale hol h a tert butyl al h l l e bee p p ed W th g i j tio m ble lug p e n b a h ed b t n tl l d f llow ng s by g je t n p es u es n th ra g f 3000– 4000 p b add ng e taın g s mp n ts to th nj t n r am

An th m th d f r ed cing ap llary f e is th dd t n f f i mat ial t a w t r flood m i g o l m h w ld m e g e with d r g t Th pri p l d ad an t g f ng l t i th s th y a ad rb d n the rv o k Ther n t e o i nles m a n b l d f r c ti nally de b- ng pl c ng the f t nt Oil p p d dd t es wate fl od ng ol bl g h bo d d

Oth p ime t l m thod are th th rmal n l tu mbu t n m th d A fi e o c mbusti n n ore t t rted n th eserv at n nje ti n ell B th nt ed t od t of g ta g s g n th rm t alt ppo t mb t n th mi t w dr en th ugh th es rvoi t w d th produ t on w ll A the mi n t on w m es f rw d p rt f th il s d till d d d i f rw rd p t f th l t b rned t p od e th h t ec y f r t g the mb t d

M h l bo at ry res h h been done n the p posed w r m thod f econd ry e- c ery nd n merous field te ts are now under wa to exam ne all of the e meth od None f th em an be aid to h e r ach ed the s ge of technol y where their ffe ti e n e can be predi t d wh ere th factor c nt oll ng the ec nomics can l d line t d

Se OIL AND GA FIELD EXPLOITATION PETRO- LEUM RESERVOIR ENGINEERING [J C C]

B bli aphy American Petroleum In titu te *Seco dary Recovery of Oil in the Unit d St tes* 1950 J C Calh un Jr *Fundamentals of Res r i E gi e ring* 19 3 M Mu kat, *Phys cal Principl s of Oil Product on* 1949 L C. Uren *Pet oleum Prod ction Engine ing O l Field De lopment* 4th ed 1956

Petrology

Th tudy of r ck the r c urren e c mp ition and o gin Pet o r pl y i oncerned pr ma ily w th the d t iled de cription and clas f ati n of r k whereas p t ol gy d al p r marily w th rock f rm ti n o p tr gene A pet olog cal de c ip- t n l de defi ition of the un t in which the k c r its tt tude and tr cture it mineral ogy and chemical omp ti n and c nclu ons re a d n t orı in In a re t t d e e h w er p trol g h m t empha z the study of ock in the fi ld and hand spe me s, with t re c u e to th microscope F r a di cu n of m ne l ident fication pet g aphic a aly i and the cl f at n f ocks ee MINERALOGY PE TROGRAPHY ROCK

Igneous rocks Extru e (effu) ig eou r k r ach th f n th r thr gh fis re of con de bl l ne r e te t (fis u n upt n) o thr u h p p l k h nnelwa s ar und wh h vol can es ar bu lt Extru i mate al may fl w out r l ti h qu etly a l va o n may be plod d as pyr l t c mat i l F ur e pt ns are gene all q t d pe ted n lo g per od of t me t b ld p thick platf rms f con de ble n tent con t n h fly of ba lt In th rthwestern U ited Stat th Columb a R r Plateau b lt in th s w y mb a s 00 000 m in Id h Oreg n and W h gt n and l l are s ha an aggr gate th kn f 5000 ft Se VOLCANO

V l a c tru t are of a va ety of type (T bl 1) l a flows may b ch a ter ed by a m th o r py u f e th p om ent flow tr c t (paho h) o by a jumbled bl ky s rfa (a) Fl w mmo ly how col m r jo nting hi h l a b en p d d by c ntra t on up n r t lli at A l va t gu ol d fie fir t alo g t upp u fa ag i t th a r and along t b ttom c nt t w th ol r rock l v ng c ntr l t eam wh h s t ll l q d flow ng n a t n l of n wn e tru t n W th uffi t lope th t eam d i aw y l a i g ca ern pa ag way V l n a t ty r es g e tly n nt n ty durat n p riod betwe n e upt and q a t t e f g l uid o k and s l d fi d f gment xpelled Th m mporta t fact r flu g

four spot pattern is obtained. Nine-spot patterns are five-spot patterns with additional injection wells added at the midpoints of the sides of each injection well square.

The spacing between injection wells and production wells will depend upon local physical conditions of the petroleum reservoir and upon economic factors. The resulting well densities will range generally from one well per acre to one well per 40 acres. Spacing economics is controlled by the amount of gas or water that can be injected into or produced from a single well. The prediction of the amount of fluid which an injection well will handle is therefore one of the most critical technical points in planning a secondary recovery project. This amount of fluid will depend upon factors such as the permeability of the reservoir rock, the viscosity of the reservoir oil, the fraction of the reservoir pore space that is filled with oil, the thickness of the reservoir formation, the reservoir pressure, and the available surface pressure.

Factors of effectivity. The efficiency of a secondary recovery operation is determined by the effectiveness with which the injected fluid displaces oil from that part of the reservoir which it invades and the degree to which the injected fluid can be made to invade all parts of the reservoir.

Displacement and retention factors. Even under the most favorable conditions of fluid invasion, it is not possible to replace all the oil in a given segment of reservoir rock. The rock contains a complex and interconnecting assemblage of small channels which are not uniform in shape or in size. Hence it is possible for the invading fluid to bypass and trap some of the oil-containing channels or oil globules. This residual oil is held in place by the strong capillary forces that are operating. On the basis of its oil retention properties, a reservoir rock may be classed as either oil-wet or water-wet. In the former the residual oil may be held as a film or as filling the most minute pore spaces. In the latter the residual oil may be held as trapped globules or islands within the larger pore spaces.

Fluid segregation problems. Because oil is less dense than water and more dense than gas, there may be a segregation of injected water to the bottom part of the reservoir or of injected gas to the top part. In either case the injected fluid will advance toward the production well through only part of the reservoir. Complete entry of the invading fluid to all parts then is not possible without production of large amounts of injected fluid from the production wells, a procedure which is necessarily costly. The possibility of encountering fluid segregation may lead to the deliberate locating of wells so that injection of gas is to the top of a reservoir structure or injection of water to the bottom, thus making use of the segregation tendencies. This cannot be done, however, in flat thin reservoirs.

Reservoir rock properties are seldom uniform, and in particular the rock may vary in its permeability that is, in its capacity to conduct fluid. The injected fluid will take the path of least resistance, and by the time it has invaded the higher permeability channels completely, it will have invaded the lower permeability channels only partially. If the permeability channels are sufficiently stratified, special well completion techniques can be used to promote uniform fluid invasion.

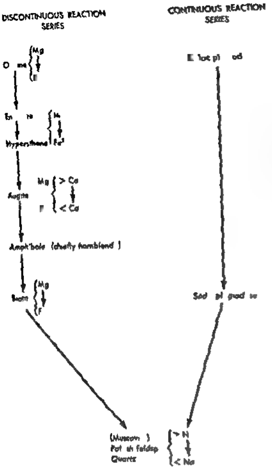
If the resistance to flow is higher for the oil in the reservoir than for the invading fluid, the invading fluid will seek the production well by the most direct flow path. As a result, injected fluid will reach the production well before all of the pattern area has been invaded. The area of a pattern which has been invaded by the time the invading fluid breaks into the production well is termed the areal coverage of the pattern.

Mobility ratio and area extent. The ratio of flow resistance between injected fluid and reservoir oil is known as the mobility ratio. With a mobility ratio of unity, the area coverage for the five-spot pattern is 72.3%, for the seven-spot and four-spot it is 74%. Each pattern has a characteristic coverage for each mobility ratio. When the flow resistance of the reservoir oil is extremely low, the coverage will approach unity for any type of pattern.

As the flow resistance of the reservoir oil increases in comparison to that of the invading fluid, the achieved areal coverage will decrease. For this reason injected gas generally produces a smaller areal coverage than injected water. However, because of the more favorable economic factors for handling gas, the injection of gas can be continued for long periods of time after gas arrives in the production wells. After water arrives at the production wells, water injection generally can be continued only until the ratio of water:oil volume reaches 1:100 or less.

Oil recovery and residue. The percentage of oil recovered by secondary methods will be a composite result of the effects that have been noted, namely, of the geometrical arrangement of pores and the capillary forces, of the gravity segregation, of the heterogeneous nature of the reservoir, and of the areal coverage that can be achieved. Under the most favorable circumstances, one may expect residual oil following secondary recovery to be as low as 15–20% of the pore space. With some of these factors operating to a disadvantage, residual oil following secondary recovery may be as high as 50% of the pore space. The residual oil will be highest where rocks have complex pore structure, where the reservoir oil is quite viscous, or where there are wide variations in reservoir permeability.

Hazards from fluid contamination. In water flooding considerable attention must be given to the purity of injected water. The reservoir rock will act as a filter to remove suspended material in the well bore and clog the formation. Hence no suspended material can be permitted. Even dissolved material will filter in some rock formation and ed the



Re ct f B w (m d fi d)

d ff t mp t t xt re r l m a a l t the r te of d t n The d el pme t f m t d m t ry ro k pr ce ed t the f ll w g t ges (1) Th a ur k any ld f ga ed m nt pply of org nically r g nated mat l (2) By weat g th ld r ock mecha call e mmin ted h m cally al t red both t f rm n l d t d rfi r l ock d l ll d m tl (3) Pa t l are t po ted l tr m oc l lake u nt w d gl by th d re t a t n f gra ity wh h es r rt l t ld d ll d wn lop s (4) M t al m d by oll ng u p n on olu t d po ted and (5) Dep t all re lid ted l y th p oc e f e m nt t on t a d t es) mp t t hal nd ecry tal l zat n (limest e) Ch m al hange ce m p sing l d t a term l d ge tic W ath ed mate l of t p rted m y be me a d l ed m rock (b tte) Sed m nta ock r d po it d e ther n l nd ea (c t tal) oc w t (m) M t ma n sed m t t n t kes pla n th hmar t f th t ents alled conti ntal hel es Examples f type f ed m ntary d po t e l ted T t l 5 Fe t res f a t t lly f nd in s dimentary ocks t addition to tratification ar cro bedding oncretions ripple marks mud ra ks and f ls See DIAGENE IS SEDIMENTATION (GEOLOGY) WEATHERING PROCE SE

A f rmation which t th l a t unit f tratig raphy s a re of rock dep ited during a sp c fic un t of ge logic time and con i ting e ther of a parti ular rock type r f eral typ de ited in a edimentary cycle Such a cycle is the chang ng qu n e of deposits reflecting f r example d an e o retreat f marine wat r n a par t c lar rea H we er while s nd t ne may be depo ited at ne time in o e pla e in th edimentary basin limest ne may b formed multaneou ly l ewhe e Su h lat r l var ation in a f rmat o eferred t a fa ies See CYCLOTHEM FACIES (GEOLOGY) STRATIGRAPHY

By mean f detailed tudie f the fo ls f a format o a d its lithology ompo itio tru ture nd d t ibution the pal ecology of the area may be rec n tructed Corr l t on f fo mat on t at tempt d cl fly on the ba i f foss ls w th sup pl me ta y d ta f om the l th l y tratig aph c t n s luble residu (in a d lubl rocks) h avy detrital m n rals (in cla tic rocks) and n

T bl 3 Igneous rock t n soci t ons

N m	M rock types	E ro m t
Ore ni Ol basalt	Ol basalt, m t chyt pe d t t	V lca l d f d ep oc ba
Alk l t cans	( ) Ol basalt, t hyt pho- f t (b) Le t basalt, t f yb salt, tra hyt ( ) Sp l t k rat phyre	(b) N rog co t t l g ( ) Oroge co t t l r gi f rm geosy l es
Th l t e basalt	Basalt (ge lly ol e-f ee) t d base	Co t tal pl t u as
Cal lk l lca	A des te, hy l te, basalt	Co t t l orogen
Lopoliths	N rite, gabbro a orthos t pe d ut	Lopol th th d ff t ted sheets
Alp e-type perid t tes	P rid t tes, rpe ti tes	O og e es
P ecambri thos t	A des l b d t thos t t y nit m nit	D med pl t f m (a n Pre- mb t ra es
C t bath l th	( ) S mpl t gra od t (b) C mpl g b fro t l te gr od t gr nit	P ec mbri h ld co ea f m t ges
M gr t tes	Gra t (som l k t j q t ye- n y d rit	Hyp byss l, m t ges d th t liers
S ph l y t	F ld p th d l rock bo t tes	(1) E mpl plu t ( ) R g com pl es
Lamproph y re	M tt k rs t t mpt t	D k w rm

the e differences are (1) chemical composition of the magma (2) amount of ga di olved in it (3) *extent of cry tallization or cooling before* eruption and (4) configuration of the conduit and depth to the magma chamber *See* MAGMA

Intru ive igneous rocks occur in many different type of units or intru ive ma e which are cla i fied chiefly by their hape and tructural relations *to their wall rocks (Table 2) Bodies that cry tal* lized at great depths (uch as batholiths) are re ferred to as plutonic th e consolidated under *shallow cover are designated as hypabyssal See* PLUTON

The crystallization of the larger intrusives may *result in profound alterations in the adjacent wall* rocks (exom rphi m) Where stocks and batholith have invaded edimentary rocks an aureole of con *tact metamorphi m is developed This result from* recry tallization under increased temperature and may be accompanied by chemical transformations *(pyrometa omatism) produced by hydrothermal* solutions generated during the latter stages of magmatic differentiation Where batholiths have been intruded into rocks which are already re gionally metamorpho ed the contact rocks formed are injection gnei ses or migmatites *See* AUREOLE CONTACT

Igneous rocks make room for themselves by force ful injection (dilatance) by engulfing wall rock blocks (magmatic stoping) or by subsidence of overlying rocks The hypothesis of granitization maintains that granites result from the wholesale transformation of edimentary or metamorphic rock layers by solutions operating through mineral replacement or by ionic emanations acting through solid diffu ion *See* GRANITIZATION

Blocks of wall rock in luded in an intrusive mass are xenoliths their partial destruction by reaction may produce irregular clumps of mafic minerals called chlieren In some instances such endo morphic effects are sufficiently intensive to result in modification of the composition of the magma (yntexi) *See* XENOLITH

Crystallizing under equilibrium condition early magmatic minerals react with remaini g fluid to yield new species *(see diagram) Interruption of* the sequence will yield liquid fractions richer in silicon dioxide alkalie iron and water than the *original magma and crystalline fractions* richer in calcium and magnesium than the parent magma (magmatic differentiation)

Igneous rocks occur in clans or associations which pos ess characteristic trace elements and appear in specific structural provinces (Table 3) The origins of various igneous rocks are sum marized in Table 4 *See* PETROGRAPHIC PROVINCE

Sedimentary rocks With the exception of ma *terial depo ited by glaciers* (till or the consoli dated form tillite) edimentary rocks how bedd ng or stratification This separation into generally parallel layers (beds strata) re ults from orting acco ding to grain ze dur ng *depo ition from*

Table 1 Types of volcanic structure

N me	Cl racte t cs
Sh ld	Low h igl t, l o l a a f rmed by u c ssi e fl d flow ccum l t ng ro nd gl cent al l
C d con	Co of mod at w th ape t cated c l n pl gently lop g s des compo d of pyrocl t pa t l s, u lly poorly consol d ted
Spatte con	Sm ll teep-si led co w th well-d f ed t composed of pyrocl t c pa t les, well consol l ted (ggl m rat)
St toco	Composed of i t rlay ed flow s d py rocla t cs fl ws f m s les (fl k fl) con mo l l k sw rm l ghtly co ca e i prof le w th central c t
C ld r	B s of gr t s z b t l t ly h l l w l med l y e plos decap t t of st tocones coll p t t u d ly g magm a l be n both
Il g-dom	Dom l p les of co s (ally l y l t) lava grow ng by ubsu face ccret nd ccon p ed by o t f gm t t on
Crypt olc t u t es	C cul a of h gl ly f ct ed rocks g ns g lly f of oth tru t l di t bances bel ed to h f med tl by s lis f ce xplos k g f cyli dr l rock m sses o r m gm cl ambers

Table 2 Cha acte istics of intrusi e ign ous ock masses

N me	Sh pe	Str l l t t w ll rock	S l oth f t es
D kes	T bul l nso d	D cord nt	F w feet t h nd ed f m les l g
S ll	Tab l l nso d	C cord nt	Up t s e l h n l ed feet th k
Lacco- l th	Plan -co e r doubly co x l ses	C e lly co co d t	1–4 n l d l tho d f et th k
V lcan neck	P p l k	D co dant	F w h dred f t t d l co of rod l l ox
Stocks	Ir gula w th st p w lls	Cross tt g	S ll bath ol tl or t g w rd pro- ject n o t crop l s tl 40
B tho- l th	I r g l r co t t d p st ply utw l bottom kn wn	(1) D co d nt ( ) C co d t n g l n y l ss tt n d t l	S o 16 000 n o pos t t f d pe- trol gy
Pl t	I eg l	U lly ros tt g	U lly l g l g l m f m s th t d t f t oth l f t

metamo ph c rocks a w ll The ompl ity f the poss ble metam rph c m neral as embl g s t ms not nly from the a i ty of po ble p rent rocks a d f om the impo m n f the eve al kind of metamo ph m b t al fr m ariati n n the in te ity of pa t cula typ of metamorph m (grad) and fr m th diffi ulty of adily ach e i g h m al qu l b um thro gh olid tate rea t on Va u fe tu e cha a t ri tic of metamorph rock lude foliati n (slatv clea g s h stos ty and gnei s tr tur) lineat n ba di g and el t t tu e S e METAMORPHISM METASO IA TI M

The f c e r n ipl is employed in ttempt n t r on t u t th e r nm nt u de wh ch a met am rphi rock wa d l ped A metam phic f c c s st f all o ks witl ut r pe t t hemi al mp t that ha e b en recry tal l z d u d r q lib um with n a p rticul r en i me t of t e t mp r ture l ad nd l ti Th fi t tw fa to s a e c ns de ed itic l The f ies a e n med fter metam rph c r cks deem d diag ost f ch restr cted co d ti ns In p act o e ig s a gro p f r lat d ro ks f d ffe nt omj t on t a part ular fa s up the p e of u h k y a mbl ge

A F e f t m tamo ph sm Lo d pr su e lo g n rally 100–3000 ba s Wat r pre su h ghly r able n ome ca e p s bly exc ed g l d p e i f w e ery low F s l ted n rd r f r g tempera t f r gi en a ge f pr ure ditions
1 Alb te p d t h nfel (f me ly lb te ep d te amph b l te f e act nolit p dote h nf l bf ci)
2 H rnbl nd ho nfel (forme ly mphibol t fa i e rd e ite-anth phyll t bf c s)
3 P r e h nfel
4 S nd ite—c esp nds t m n m m pr s- (l d P P o) nd max m m t m pe atu – y om tam ph m

B F f eg al m tamo ph m Load nd t p es g ne lly qu l h gh (3000–1 000 b) Fa listed n rd r f in eas- g t mp at e and p e su
1 Zeol t (h th t not ec gn zed)
2 C ee h t
 a Q rt alb te-mu it chl te (f me ly mu it -chl ite)
 b Q rt lb t b t t (f rme ly bi t te- sc t)
 Q t lb t lm d e (f m ly alb t p d te mpl bol t fa i hl t d l m d e bf)
3 Cl pt h r (h th rto of ncert i t t P o l q at d w th th g e h t (a t th gl u ph ne sch ts nd th oc tes m t p sent a d rg t l f m t m ph m nd t ed by de el pm t f u lly h gh p es e at l w t mpe t)
4 Almandine amph bolite
 a Staur l te-quartz (fo merly staurolite
 b Kyanite muscovite quartz kyanite)
 c Silliman te almandine
5 Gran lite
 a Hornblende granulite
 b Pyrox granulite
6 Eclog te

Reg onal a iat ons in grade may b mapp d by mea s of i g ad l es formed by the inter ection

Table 5 Selected xample f ed me tary d posit nde va io nm ts

Ag t	D pos t	Res lti g rock
Cont tal		
St eams	V ll y f ll	Sand to
	All l f	gl rate
	D lt	S lt t
Lakes	V ed l y	Sh l
Sp s		T
		S l t
Sw mps	P t	C al
Wind	D	S d t
	D t	Loess
	V lca h	T ff
Gla rs	M	T ll t
Gro dw t	St l t t	D pst
G ty	T lu	B ecc
	A l h	C gl m t
	La d l d	
M n		
Bre k rs d l gsh cu re ts	B h	S d t
		Co gl m te
Lo gsh curr ts		S d t
		Sh l
M m ga m	Reef d th sh ll d pos ts	Sh ll l mest e
		Coq
		D t
M w t	E po tes	R lt
		Rock hyd t
M n w t	Coll d l p c p tates	Phosph t
		M ese d co cr t ns
		Ch rt

T ble 6 Types f m tam rph m th f ct rs a d es lts

Type	F t rs	Ch g ock
C ta l t	St ess, l w hydro t t press	Fragm tal g t t
Co t t (th rm l)	H t l w t mod hydrost t ess	Rec y t ll t w l co rs g ly m lt g
Pyrom t so t m	H t, dd t by droth rm l sol t ns, l w t mod rat hydrost t p ess re	Reco t t t m ral l g ock compos t
R g l (dy m)	H t, w k t tro g t ess, mod t t high hydrost ti p es dd t sol t	Rec y t ll t w m ls co rse gr ns p ral l l n t t f m eral t prod f l t

drill holes by electrical conductivity, radioactivity, and seismic wave velocities.

Metamorphic rocks Metamorphism transforms rocks through combinations of the factors of heat, hydrostatic pressure (load), stress (directed pressure), and solutions. Most of the changes are in texture or mineral composition; major changes in chemical composition are called metasomatism. The major types of metamorphism are presented in Table 6. Rocks that can serve as parent material for metamorphic derivatives include both igneous and sedimentary types and, less commonly, older

Table 4 Synopsis of magmatic evolution

Primary magmas	Mode of origin	Common types of igneous rocks		
Alkaline olivine basalt magmas	By differentiation and plutonic crystallization	Teschenites, Theralites, Essexites, Shonkinites, Pyroxenites, Picrites, *Peridotites*	→	Syenites, Nepheline syenites, Ijolites → Carbonatites
	By differentiation and volcanic crystallization	Mugearites, Trachybasalts, Olivine basalts, Picrite basalts	→	Alkali rhyolites ↑ Trachytes ↓ Phonolites
		Nepheline basalts, Soda lamprophyres, Melilite basalts	→	Phonolites
	By contamination involving reaction *with granite of* continental basement	Leucite basalts, *Biotite lamprophyres*	→	*Leucite phonolites*, Latites, Trachytes
	By differentiation and modification *in geosynclines*	Keratophyres, Spilites		
Granodiorite granite magmas	By differentiation and plutonic crystallization	Granites, Granodiorites, Tonalites, Diorites, Syenites	→	Pegmatites, Aplites
	By differentiation and volcanic crystallization	Rhyolites, Dacites, Andesites, Latites		
	By mixing with basaltic magma	*Andesites*	→	Dacites, Rhyolites
	By assimilative reaction with slates, limestones, *amphibolites*, etc.	Syenites, Nepheline syenites; Diorites, Tonalites		
Tholeiitic magmas	By differentiation and plutonic crystallization	Granophyres, Diorites, Anorthosites (Bytownite), Gabbros, Pyroxenites, Peridotites		
	By differentiation in thick sills	Granophyres, Quartz diabases, Diabases, Olivine diabases		
	By differentiation and volcanic crystallization	Tholeiitic basalts, Picrite basalts	? →	Rhyolites, Andesites

F. J. Turner and J. Verhoogen, *Igneous and Metamorphic Petrology*, 2d ed., McGraw-Hill, 1960.

unt l th d el pm nt of ch ap ch n rly in the n n te nth ntury pe te was y omm nly ed th gh t Eu r and Ame e f r de a te mug t k rd bowl d he ca dlesticks nd a te s Th fin r g ad tl onta ning the mo t t n w r l u ed in aki el iou s d i ic essel u h a mm n plate cl al i es and c uets a d ymbolı e p ad fla
S Try [c c o]

pH

A t m u d to de c l th l yd oge n actı ty f y t m It ı d fn d by the xpre ı pH = −l g a ın wl h a ı the ct it f the h d o gen In d lut oluto the a t ıty is e en t lly q l t th n entrat n s d the pH may h app mat ly defin d a pH = −log [H] wl e [H] th oncent at n of th hydr gen m le p r l t r The u e of th pH mak s t p ı e p t nnece ary n d sc ibing the h d gen ı t ty l sv t m n whi h ıl hy d g n cti ıty ı m l l te tl e pH s 3 The te m t ord n r ly u ed to d c b solu t ı wl h the hydr g ı n ct ıty o e o g ı
Th xp n d f ng the pH l ely r l t l t th l e g l th hydr en ı w th esp t t t dard eference t te S ACID AND B F CL ELECTR DE HYD OGE EL CTRODE HYDRO E I N [V J J]

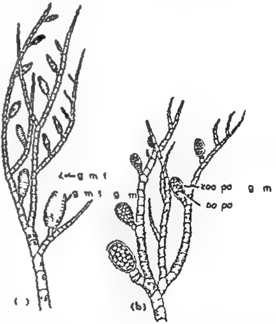
Phaeophyta

Th pl t al lled br lg e ar o har ct t ll m t ne th t th l ger m r be ar mm ly k w b w eawe d kelp Th d l d t ut d b t e m t ume n tl e ock t f tl lde e ll w e th m n th p n e n muddy alt w l a p phyte e d phyte Many a bl ı tl t nd tl e d t f th ı te t lal h r th m ı m t uo ly t m ged \ f w g a m l f nd at d tl d ı th B tl nn } nd p n al pec h be d ed Th y r d t g h d f m th alg l tl l g n l by tl r du t d by th t ı tu e f th pl t l l
Th t n l t d l y m rked pr d mi f x th ph ll lud ng l ı x th n th ll l b n l m ı pl ec d the t gm t m k th f th hl ophyll (s C R TEN C t R PHYLL) Ca bohyd t s ar t r l t a t l l t l l l g m ll n th f m f th pol h de lam na ı d th l l l m t l

Economic importance Alth gh l gl l l m r t F pe d n tl Am r a al f th l lg c l d h m food n th O nt h J t a and th l nd r d g tl Ch n Se H L m a Ala nd th r k lp rd t l w t Th ma l ed w m ked th t m v l d ed d pack agel l ı g es th k ı g soup nd for mak ng waf r cake or other confe tion Dur ng th w r yea the kelp were gatl ered a d p d t p oduce organic c mponents called alg in t (salts of alg nic ac d l tained fr m tl e colloidal gel alg n conta n d in k lp) Alg nates re widely u ed n th ce cream baking rubber a d p nt indu tries The algin tes are also sed as u pend ng agent n a wide v r ety of pl armaceu t al

Reproduction All f th Pl ae phyta ha e an al ternati n f generat on tl at s a defini alte na t on f ual a d a exual ind vid al Th plant whi h devel p th g mete (e ell) ı alled the gam t phyte and that which p od ı e the a e ual po s is termed the rophyt Th game t phyt f th g up may be mall flament ı d inc n p uous ı ll may n t diffe markedly f om the p phyte In s ch f rms a tl e Fuc le tl e ga n t ph te ta e is ob urely repre nted by a ne- elled r productive ag nt the g met This l ng patter of alt rnat n f gen rat ons with the algae on de ed imp rt nt in e it is hara te ı t c f all l gl er pla t
f ear haped m t le repr du ti e ll with two late l fl gell are cl a ter tic of tl e phyl m Sexu l eproduct on is ı oga ı r gam u l g a all ct ve m le gamet and a l rg n nmot le g A xu l reprod t ı ac m pl hed by fragm tati f the tl llu r in m st spec by oo p r (sw mming p re)

Morphology Th plant b dy alway multi l lular nd ma vary fr m s mple flament u



Fg 1 E t p ( ) B h d fl m t b g m l ll l g met g O g m t g m i l g l b fl g ll t pe sh p d g m t (b) B o h d fl m t b g ll l po g w th p (F m H J F ll a d O T pp C ll g B t y d H h 1954)

of planes of i e metamorphic intensity with the earth surface The e are defined on the appear ance of a pecific mineral known to reflect a major increa e in the inten ity of metamorphi m

The primary cau e of tre e acting during regional metamorphi m is dia trophi m of the mountain building type The higher temperature may re ult from deep burial owing to the ge ther mal gradient of the earth in part to concentrati n of radiogenic heat or in part to heat supplied by cooling ma of magma In contact metamorphi m this la t is the sole heat ource *See* GEOLOGIC THERMOMETRY

Once formed metamorphic rocks are ubject to further change through folding and crumpling of the foliation and through exten ive injecti n of igneou material to form migmatite [F W H]

Bibliography T F W Barth *Theoretical Pe trolo y* 1952 W S Fyfe F J Turner and J Ver ho gen Metamorphic reaction and metamorphic facie *Geol Soc Am Memoir* 73 259 1958 E W Heinrich *Microscopic Petrography* 1956 P Nig gli *Rocks and Mineral Deposits* 1954 F J Turner and J Verhoogen *I neo s and Metamor phic Petrolo y* 2d ed 1960

Petromyzontiformes

One of t o orders of Recent jaw le s fishes contain ing the lampreys This order al o known as the Petr myzontia They are degenerate modern repre entative of the plated cephalaspidomorph of Silurian and Devonian time Lamprey differ fundamentally from the uperficially similar but rem tely related rder Myxiniforme or hagfi he The n ut i produced and overlies a circular oral di k that bears cornified teeth and lack enlarged barbel the single nostril i located n top of the head bef re the eyes and doe not penetrate the palate there are e en pairs of pl erical gill pouches that open internally into a re pi atory tube and externally through seven pairs of pore the one or t o dor al fin are more or les di tinct from the caudal fin and there are two pairs of emi circular canals Lampreys are bi exual animal that li e permanently in fre h water or enter streams to breed Egg are deposited in gra el riffle and the young develop into blind lar ae that burrow in the oft bottom and feed for everal years on micro organisms strained from the water At metamor phosis the oral disk and eye devel p and the tran formed lampreys become free s mmin

Sea lamp ey Petr myzon m s (Aft G B Go d Great I I t o of F he es h b ti n L nd 1883 U S N tl M e m B ll 27)

Some pecies known a brook lampreys remain in treams for a few month without feeding then breed and die Most lamprey however are para sitic feeding on other fi he and growing for a year or m re bef re they breed and die A protru ile tongue armed with horny teeth employed to ra p an opening in the ho t s body from which blood i sucked So de tructive are the e para ites that after gaining recent acce to the upper Great Lake the ea lamprey (*Petromy on marinus*) all but exterminated the lake trout and other valuable commercial fi hes

Lampreys are cla ified in a ingle family Pet romyzontidae with genera and about 30 pecie They are chiefly inhabitants of temperate and cold temperate waters in both the Northern and South ern Hemi phere *See* CYCLOSTOMATA (CHORDATA) [R M B]

Pewee

A name usually applied to the wood pewee *Con topus virens* a moderate ized flycatcher of the family Tyrannidae This du ky fore t flycatcher can be di tinguished from its relatives by the ab sence of an eye ring and the pre ence of t white wing bar Its clear flutelike call pee a wee

The wo d p w Co t p le gth to 6¾ (F om E L Palm F ldbo k of Nat al H t ry M G aw H ll 1949)

with the middle syllable the l tone i a char acteri tic ong of the east rn de iduou f e t e pecially as the fir t ong of the m rning It i replaced in the we tern f re t by the e tern wood pewee *C sordidulus* The name pe ee often applied to the ph be *Se* FLYCATCHER PASSERIFORMES PHOEBE [J D B]

Pewter

An alloy containing tin and lead u ually in prop r tion of four to ix parts f tin to one of lead Othe metals are ometimes ed th or in place of the lead includ ng copper antimony and zin P wte ha limited u e in the mak ng of ornament I are

Fg 3 ▪ ( ) Pl t w th b l d k h ldf t l d w th p phy (m lt c ll l h) b g d h t m th ll ▪ d bl dd rs fl ts d th d ( ) S t th gh f m l o pt l fl t d t p pt l Th bl k p t th l d w th p phy e d w th a f w g t l tt the p g l d g t th t ng gg (F m H J F ll d O T pp C ll g pt l (b) S t th gh m l pt l B t y d Holt 1954)

eggs p od ed t g n m a y from ight F t e S g m A me t d on t k pl the format f th hapl d egg and p rm f m the d pl d pl t Aft r the l b r t n f th g m t he n le r m (fert l zati n) u th d pl d y g te thu f rm d germi tes alm t immedi t ly S e GE ETICS [P.A.V.]

B bl gr phy S e THALLOPHYTA

Phagocytosis

A t m ed i ge er l b l gy t fe to the en g lfm t f a p t l b a ll p o impor t t n th utrit f m ny p t a nd p m t m ta a d the m tam rpho t d di po l f m tabol p d t f h gher f ms f med ph g yt r f r espe lly t th g lfm t f n ad g m ga ms by th w d ng p lym pho clear d m n l ll m ph g f th blo d d th m o-ph ges f the t ul d th f l y tem l di g th w nd g h t yt and the us fixed ph goc t ll f the pl n l lymph d ti l bo m r w Ph g yto t th o f th p im r d f m ha m imm n ty t f ti S CARDIO LLAR SYS E T M r I RO OZO

Th d g ee f pl g yt y pa t l r i t d p d f t the nat f the m c o-t l f t ed Th r l of m y l t t l ted w th th p e on f pa t l pol a l d pr t in fa om m t th t h b t phag yt The f p pe t es l q tly h lte ed by ntact th pe fi ntl l — p a t bod ol mpl m t (p n t) th t the t ed ll n w m d l ph gocyt d A ec nd f t th at f th t th f h b th m roo g n m nd ph go-yt ll est gh u f es p om t e han ed fa e ph go yt s In the body b cteria m y n the pres nc f the approp at a t body and ompleme t b ome adhe e t to p ti les ch s e ythr cyte (mmu dherenc) and in th s ondt n th y a e m e uscept bl t phago-cytos th n wh n f e

A a i ty f n eq e e m y n e n the m r o ga i ms ha b n ng lf d In ma y t c b cte i a ead ly d g st d nd de t yed if th othe fa to in path g i ty a e f v rabl t th h st f ll prot t n d covery foll w H we e m ny mp rt nt pathogen such s th staphyl c u c survi d often multi ply w th l ko yte Intrac llular m ro gan m a e ch acte st ally fou d in tul em a typho d fe e bruc ll s a d tub cul s m ng th h c d e s In th s state the ba teri m y t lly b p tected g n t th bacte dal act of ntib dy and mpl me t a well a s m alth ugh not all tib ot c Th ultim t res l t n of u h i f ti depend a compl x b l n e betwe h t a d p ra ite S ANTIBI O IC B UCELLOSIS IM U ITY OP ONIN STAPH YLOCOCCUS TUBERCULOS S TULAREMIA TYPHOID FE ER VIRULENCE [H P T]

B bl g phy E A N l n Jr Th mmune adl c ph ome n *P c R y S M d* 49 55–58 1956 E S ter f te t n betwee phag ytes d p th ge ic m c oorg m B t l Re 20 94–132 1956

Phalangida

A rd f the cla s Arachnid The membe f thi rd al k o the Op l o e r har ct d by u gm t d ph l th r b adly jo ed t gm ted abdom p d h lat h l a pa red p lp f p f gm ted l g p r of mple eye a d g t l p g bet e the f u th ox The r b d n e f m

form to a complex body having a basal attachment structure and a stemlike main plant body The latter may be branched or unbranched and of lengths varying up to about 50 meters They may be broad and ribbonlike or have leaflike branches and are often provided with air bladders The largest forms may have a relatively complex internal structure

Classification The Phaeophyta are divided into three cla ses on the basi of their life cycles The I ogeneratae are distinguished by having an i o morphic alternation of generations A typical example of this group is *Ectocarpus* (Fig 1) a genus of world wide distribution with many species It grows upon rocks or is epiphytic upon plant usually other brown algae The plant body is com po ed of branched filaments which may be 5–6 in long Each cell is uninucleate with one or more simple or lobed plastids The plant body may be either gametophytic or sporophytic (isomorphic) The diploid zygote is the first cell of the sporophytic generation which develops into the usual branched plant

Two kinds of reproductive organs may be produced by the sporophyte The terminal part of certain branchlets enlarges forming a sporangium The single nucleus of the young sporangium divides meiotically and then the daughter cells subdivide mitotically until there are 32 or 64 free nuclei (*see* MEIOSIS MITO IS) There ensues a cleavage of the protoplast into small uninucleate protopla ts each containing a single chromatophore Each of these protoplasts develops into a pyriform (pear haped) laterally biflagellate zoospore The e zoospores are produced within a common cavity which opens through an apical pore this type of porangium is unilocular Meiosis occurs in the fir t of the nuclear di isi ns so that the zoospores and the resulting plants are haploid The terminal portions of other lateral branches by numerous vertical and tran erse cell di isions may produce an aggregation of small cubical cells each containing a protoplast which may become a zoospore Each of these zoospores is formed from a eparate cell such sporangia are said to be plurilocular The zoospores are diploid and upon germinat on produce additional porophytes The gametophytic plants (de eloped from zoospores formed in the unilocular porangia) produce only plurilocular sporangia The motile cells formed in sporang a may unite in pa rs to form zygotes the beginning of a new diploid generation or may de elop asexually into plants wh ch a haplo d and gametophytic

Neither exuality nor an alternat n of generations is obligate as both the gamet phyte nd the sporophyte can be reproduced asexually Other examples of common genera belonging to th order are *Cutleria* and *Dictyota*

The second class the Heterogeneratae dis tinguished by a heteromorphic alternation of generations Thi includes the order Laminar ales the species of which are commonly known as the kelp In *Laminaria* the sporophyte is a large comple perennial plant consisting of a branching holdfa t, a tipe (stemlike structure) and an expanded blade (Fig 2) This is the dominant generation The gametophytes are microscopic branching fila ments which although free living are relati ely ephemeral Male and female gametes are produced on separate gametophytes and gametic union is oogamous It is of interest that the relation of the two generations is very similar to that found in the higher ferns and related groups

The third class Cyclosporeae is a group in which there is only a free living diploid generation There is but one order the Fucales which contains such well known genera as *Fucus Ascophyllum* and *Sargassum* In *Fucus* (Fig 3) the production of reproductive cells is confined to the tip of the dichotomously branched thallus Egg and perm may be produced on the ame plant or on different plants depending on the species As in all Phaeophyta the sperm are laterally biflagellate The

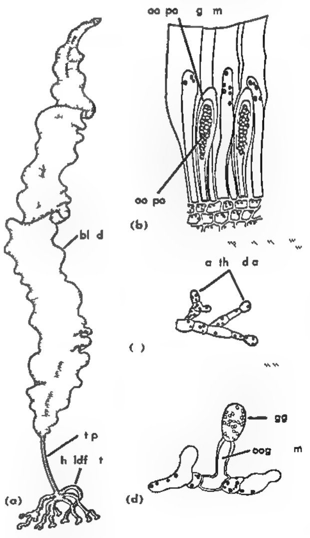
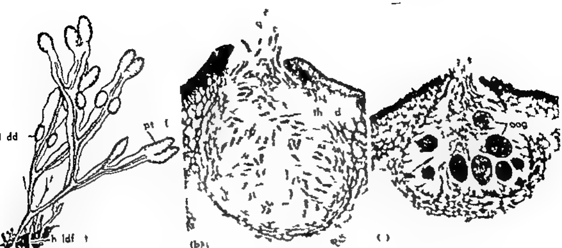


Fig 2 L m ( ) l ap w th tl k holdf t t p a d bl d (b) S t f f of bl d sh w g two o po g a w th m y p ( ) M l g met phyt w th t m l a th d (d) F m le g m tophyt w th oog m f m wh ch gg em g g (F m H J F ll a d O Tpp C ll g B l y d H ll 1954)



Fg 3 Fu ( ) Pl nt w th b l d k o h ldf t d h t m u th ll p d bl dd fl ots d fl t d t p pt l s. Th bl k p ts th l n th p g l d g t th c t pt l (b) S t o th gh mol n pt cl l ed w th pa phy (m lt ll t h rs) b g th d ( ) S t th gh fem l ept l l ed w th p physe d w th a few go n o t g gg (F m H J F ll d O T pp C ll g B t y d H lt 1954)

gg prod ced a gon m ry fr m ght n F s t o S gas m A me ot c d to takes pl e the f rmat l the hapl d egg nd pe m f om th d pl d pl t Aft r the l be ati n f the g met hen u le (fe tilizat on) oc the d pl d zyg te thu f rmed germ nates alm t imm d tely S GENETICS [P A V]

B bl g aphy S e THALLOPHYTA

Phagocytosis

A t m u ed g ne al b logy t r f r t th en g lfm t f p t l by ll a p oces mp r t nt n th n t tio of many p to a d pr m t met d th m t m ph nd d po l f m t h l p d t of h gher forms In med ph g yt refe e p ci lly t the g lfm t l n d m roorg n sm by th w d g p l m ph n l r a d m o ule ll m phag f the bl od a d th m ro- ph ges f th l nd th l t y t m lud th d g h ti st nd the o s fixed ph g t ll f th pl n l r lymph d tis- d bo marr w Ph g cyt s th o e f th p mary d f n h ms mm n ty t f t S C RDIOVA C LAR SY TEM MET O P O

Th d g ee f ph gocyt ny pa t ul t l p nd fi t the t e f th mi t l s f t d Th r le f m y t r l l ted w th th f p t l p l h d p t n f m po nt th t h l t ph g yt Th f p pert n f q tly be lt ed by t t th pec fi t l d n p n t bod n mpl m t p n t th t the t ed ll w m r d ly ph g yt ed A er d l t th f the t th n wh h th m oorga m d ph go- ll t gh f p m t a h n d u fa e pha ocyt t I the b dy bacteria may i the p ence of th appropr ate antib dy d c mplement bec me adhe ent t part cles s ch a e yth ocyte (mm ne adh rence) nd in thi o d t they a e mo s c pt ble t ph go cyt si th n wh n f e

A v ri ty f c n equen s may e s n e th mi ro rg n m ha be n ngulf d In ma v in t es b ct a a readily dig sted a d de t yed if th othe fact r n p th g c ty a fa rabl t the h t, f ll p ote tion and r y foll w How e m y mp rta t pathogen uch th st phyl c c us an rv e and often m lt ply w th n l kocyte Int acellul m oo gan ms a e ch a t t ally f und in tul m a typh d f er b ucell and t be l am ng oth h c d a e In tl s t te the ba te ia may tu lly be pr t ted g in t the b teric dal t of antibody d c mplement s well as s m alth gh t ll tib ot c The ult m ate l ti n f u h infect o d pe ds n a c mplex b l ce between h t d p r t See ANTIBI OTIC BRUCELLOSIS IMMUNITY OPSONIN STAPH YLOCOCCUS TUBERCULOSIS TULARE IIA TY HOID FE ER VIRULE CE [H P T]

B bl g aphy R A Nel Jr The imm adhe pl en me *P c Roy Soc M d* 49 55–58 1956 F S t Int racti betw en ph g cyt nd p th n m ga ms Bac te l R 94–132, 1956

Phalangida

An de f the cl s A h d Th m b f th d l kn wn a th Opl o a e ch te z d by n gmented phaloth x b o dly j ned t egm t d bd men p red h l t hel e pa r d palp four p f egme t d l g pa f mpl) nd gen t l pe ng b tw the f u th se The b d e r g fr m

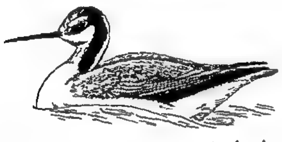
less than 1 to over 15 mm in length. Respiration is by tracheae. Many species possess scent glands whose openings are at the anterolateral portion of the cephalothorax. These emit a material with a pungent odor. The phalangids lay eggs which hatch into forms resembling the adults. Their food consists of vegetable matter and soft-bodied insects.

While members of this order are found throughout the world, they attain their greatest abundance and diversity in the moist tropics. In these regions they are often bizarrely spined and possess elaborate dorsal color patterns. In temperate areas the species are drab and often have long spindly legs. These are the forms popularly known as daddy longlegs or harvestmen.

There are three suborders: the Cyphophthalmi, small mitelike forms; the Laniatores, with flattened, often colorful bodies, found chiefly in tropical areas, some species adapted to cave life; the Palpatores, including the long-legged forms found in temperate areas. Common genera are *Leiobunum* and *Phalangium*. See ARACHNIDA. [C J GO]

Phalarope

Any member of the family Phalaropidae, consisting of three monospecific genera. They are shorebirds but differ from sandpipers in several respects. The toes are webbed basally and have lateral membranes, as in Wilson's phalarope *Steganopus tricolor*, or with lobed margins as in the two pelagic marine species. The female is the larger and more brilliantly colored. It is also the female that does the courting and selection of the nest site, while the male incubates the eggs.

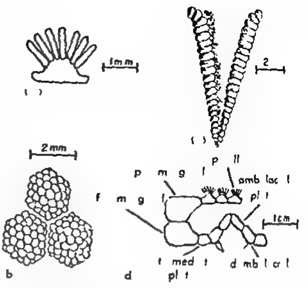


The Wilson phalarope, *Steganopus tricolor*, length to 10 in. (From E. L. Palmer, Fieldbook of Natural History, McGraw-Hill, 1949)

All three species nest in the Northern Hemisphere. Wilson's phalarope is found in the marshes of the Great Basin and Great Plains, whereas the two marine species are circumarctic. The northern phalarope *Lobipes lobatus* and the red phalarope *Phalaropus fulicarinus* are both capable swimmers and may stay away from land for indefinite periods, including most of the winter. See CHARADRIIFORMES; SANDPIPER. [J D B]

Phanerozonia

An order of Asteroidea in which pedicellariae may occur but are not the crossed type and in which the margins of the body are defined by two conspicuous series of marginal plates, one placed vertically above the other. The marginals constitute



Diagnostic features of Phanerozonia. (a) Paxilla in side view. (b) Three paxillae in surface view (Pseudarchaster). (c) Arm of Astropecten primigenius showing marginal plates and paxillae in transverse row. (d) Transverse section of arm.

a buttressing skeleton which is usually more robust than the ambulacral skeleton. The upper surface is covered by symmetrical rows of plates which often bear brushlike clusters of spines, the paxillae. Papulae are restricted mainly to the upper surface. The tube feet lie in two series in each ambulacral groove. Pentamerous symmetry is more constant than in the other orders of Asteroidea. The order is represented by Paleozoic fossils (suborder Pustulosa) and by three other extant suborders. See ASTEROIDEA; NOTOMYOTA; PAXILLOSA; VALVATA. [H B F]

Pharetronida

An order of the subclass Calcinea in the class Calcarea. These sponges have a leuconoid structure. The main skeleton is composed of quadriradiates joined together by a calcareous cement or consists of a rigid calcareous network not composed of spicules. The dermal skeleton commonly includes spicules in the shape of tuning forks or may be composed of overlapping calcareous scales. Examples of this order are *Minchinella*, *Murrayona*, and *Petrobiona*. See CALCAREA; CALCARONEA. [W D H]

Pharmaceutical chemistry

The chemistry of drugs and of medicinal and pharmaceutical products. The important aspects of pharmaceutical chemistry are:

1. Isolation, purification, and characterization of medicinally active agents and materials from natural sources (mineral, vegetable, microbiological, or animal) used in treatment of disease and in compounding prescriptions.

2. Synthesis of medicinal agents not known from natural sources and the synthetic duplication, for reasons of economy, purity, or adequate supply, of substances first known from natural sources.

3 S mt y the lled f d ugs wh reby t r l b ta ces re transf rmed by e mpar t ly *imple* teps t prod t w th m re fa r able ther peuti or pharmac t al pr pe t

4 Dete mination of th de t at e r form f a med l ag nt whi h h b ts ptimum med inal act ty nd t it s me t me lends it elf to t bl f mulation nd el gant dispens

5 D t rm t n of n ompat bil t e ch mi al d l ologi l betw en th ar u ingred ent of a pr r pt n

6 E t bl hm nt f afe nd practical tand ard w th e pe t to b th d s ge nd qual ty n rde t re s f rm and th apeut ally el bl f m f all m d c t n

7 Imp ment nd p mot on of the e f ch m al ag nt f r pre e t of llnes alle a t n f pa n c re of d ease d se r h f r n w therape t gents particularly wh r n sat f tory remedy now ex t

Ch m try n t a s fac ts along w th g t d h e f *om* the phy cal and b l g c l c es ent l for ph rmaceutic l b m s try It d ffic lt to h r te ny ind idu l p ocedu r a ti n a olely p nd rantly ph ma ti al F r xampl the p o edu e f n e ti g l f l t ether n ellent g ne al anesth t c ma with l ght m d fi at on be ad ju ted f th pr d ct n f ethyl ne n mp rtant ndu trial h m al a d th tep by whi h d p t l hydr g t d t d am n h n m th t fib r t rmed ate t eful fo th c n e n of t pt my in t d hyd t ept my *Drug* st d d at n u s many tech iqu s a d m th d f l t l hem t y

f the ni te th e tury beg n ng w th the sol t f m phi e f m p m by F W A S t n r (180) p th rs f m Einb k C ma ff rt w p im il d re ted t wa d th sol t f th ti t ent f pl t thi es lted n th d y a d de r pt n f m y alk l d gl d b hyd t lat le il d fi ed f Th t m pl t h mi try a d ph ma t f h m t w d t h g ally a d th f ld f n tigat n m n act e tod d p m t t f l g t m t m t a ti t m t d th t le tha 3 f th kn w fl a h b en am ed

Th Food d D g l g l t (1906) l d t th l d ng f r a h ti t t n lud th de l pm nt f a l t cal p oced es f r th m t t f th q l t a f pot f dr g Thes d r ti g nd exp nd g m b e th qu q n l es f the N t nal F m l n l th U S Ph rma p both f l t d d rpl m ted b tat a d fed l g l t d t t ti m thod r po l g ha ged w th th nf r m nt f the ffic l t d d S PH RMA O E Y PHARM COLOGY PHA A Y [w u HA]

B bl g phy C L J k n W H H tt ng J B D t d K F H ml n *Th Ch mi t of O ga ll d l P od t* 4th d 19

tional F rmula y Ph rmacope a of the Un ted Stat

Pharmaceuticals testing

Meth ds used t d termine whether pharma ut cals are ffica ous of standard and ons stent pr te y and pur ty and acceptabl as to olor flavor an l physical ppearance Pharma euticals are medici al pr ducts pre cribed by med cal doc to s and dispe ed through ph rmacies and hospi tals Ph ma ut c l are taken into the b dy orally or th ough pare te al injecti n usually when the p t ent s we ken d by nfecti n ill es

The t ps in the pr duct n cycle for ph rma euticals t be un formly contr lled and ach pe ati n mu t be as mpletely cu ate any othe ph e in the cycle These control pha es are comm ly st t d as (1) r w m terials (2) manu facturi g p o ed r s (3) fi i hed product t ting a d (4) cont ol of dent ty

Raw materials The e are ually r f rred to as fine ch mical and e purcha ed n sp ifics ti n If the aw m t r al fficially *recogn z d in* th Ph macop of the Un t d State o in the Nat on l Formula y the pe ificat on are p o ided n mon graphs in th omp end ums If th e raw m te i l s ot ffic lly incl ded in th e compen diums *chemi* al o phy i al spe ific t n b th a e prepared by th purcha e on th ba i of the r q r me t f r t e f n l d r duct

Phy cal pec fi atio s i f de uch h r ct r t s as b lk d ns ty n h s z l r odo xt a n us o t m nati su h as fib r an l h m ne ty Chem l spe ifi tions sually include u h ch cter ti s a hemical o phys l g cal po te y melt ng p t b il g ange pt cal t t n m stu he y metal ntent h m al dent ty and presen e f hem al nt m n ts

Sampl a t k p n re e pt f a pecifi batch f r w materi l S mpl g m y n i t f a mp te ampl c mp d f small p ti ns f m e ch o tane w thi th b tch f one o m e r nd m mall p ti n of th ent bat h The s mple o sampl re s bject d to te ti g p edure t e u c forma ce to e ch p c fic t on l dd t n to physi l n p t t e p o- ced es m ng f m *simple* melt g p int de term nat n t very c mplex h mat g aph a say Only after th r w mat al ha bee he ked aga n t ach f the spe ific t ns an t l e ap- ed f e n ph rmace t al

Manufacturing procedures T n u duct f the h gh t qu lity pharma uticals mi t b ma fa tur d u d tr tly r g l ted p edu e nd with adequ t che k d ng e h per t on Batch t k t o r a f t ng fo mula card t forth ch m n f tu ng t p d tal a d upo mpl t n f a h step th d u ll n t al d by th p ato E act p g temp r t fi m ing t m d g at d q pm nt and preci d t l f p ati u h a filtr t n mpt n a e ca full p ll d t n th bat h t k t All raw mat al a d l l heck d

for identity and quantity before being incorporated in the process

In-process assays are used to ensure homogeneity of mixing or completeness of reaction in the manufacturing process. Such assays range from simple pH measurements to complex infrared spectrophotometric determinations.

Upon completion of the manufacturing operation, batch tickets are usually checked by control inspectors to ensure that each step has been signed for. Representative samples of the bulk batch are taken by the inspectors and submitted to the chemical or biological testing laboratory for final assays. These representative samples may be either composite or random samples.

Finished product testing. Usually each batch of a pharmaceutical must satisfy four requirements. It must conform to (1) the label claim for potency, (2) homogeneity standards, (3) standards of pharmaceutical elegance, and (4) identity requirements.

Potency standards require that the batch meet label claims within specified limits. Monographs of the United States Pharmacopeia or the National Formulary usually indicate maximum and minimum limits for official products. Limits for unofficial products are established by the manufacturer and are usually modeled after those for official products. Potency assays vary in complexity from a simple test on a single component pharmaceutical, such as an ascorbic acid tablet, to very complex chemical and biological tests on a multicomponent pharmaceutical such as a vitamin preparation containing several vitamins plus minerals. Before approval biological products must meet similar complex and severe criteria for potency.

Some special types of pharmaceuticals require additional complex tests. All parenteral products intended for injection must meet sterility requirements. Frequently tests are required on these for pyrogens and for "safety" (toxicity). These additional tests are necessary to ensure that no undesirable physiological reaction will result from administration of the pharmaceutical.

Statistical quality control trend charts on certain characteristics of a batch, such as tablet weights, ampule filled volumes, or random assay values, indicate conformance to homogeneity standards. Stability tests, which are usually more complex than potency tests, are frequently made to ensure that the pharmaceutical will remain potent and safe for use during normal shelf life. Such tests confirm the absence of harmful deterioration products during the ordinary time lapse between manufacture and use.

Pharmaceutical elegance refers to the physical appearance of the dosage units of pharmaceuticals. Conformance to these standards includes inspection to ensure that solutions are "sparkling clear," that tablets are not "capped" or "chipped," that parenteral ampules are free of "floaters," and that colored products are of the right hue or shade. These standards govern physical quality.

Identity. Identity is the final requirement in pharmaceutical testing. Testing for identity guarantees that the product has been properly labeled, that is, that the right product is in the right bottle with the right label. Serious consequences would result from a bottle of strychnine tablets carelessly labeled as saccharin tablets. To maintain the identity of the product, extensive checks are made throughout the manufacturing operation, including the use of duplicate label tags on all bulk goods, and very rigid controls are applied to printing, storage, and application of labels on finished pharmaceuticals to ensure final identity.

Only when all the operations in the production of pharmaceuticals, from securing raw materials to labeling the final container, are rigidly controlled through testing and checking procedures can one be assured that the pharmaceutical is pure, safe, and efficacious. *See* BIOASSAY; QUALITY CONTROL.

[W.B.FO.]

Bibliography. W. B. Fortune, Control of fine chemicals and pharmaceuticals, *Anal. Chem.*, 29(7):17A–29A, 1957; *National Formulary*, vol. 10, 1955; *U.S. Pharmacopeia*, vol. 15, 1955.

Pharmacognosy

The general biology, biochemistry, and economics of nonfood natural products of value in medicine, pharmacy, and other health professions. The products studied are of biologic origin, either plant or animal. They may consist of entire organs, mixtures obtained by exudation or extraction, or chemicals obtained by extraction and subsequent purification.

Pharmacognosy literally means knowledge of drugs, as do pharmacology and pharmacy. The center of interest in pharmacology, however, is on the mode of action of all drugs on the animal body, particularly on man. In pharmacy, major attention is directed toward provision of suitable dosage forms, their production and distribution. Pharmacognosy is restricted to natural products, with attention centered on sources of drugs, plant and animal.

Sources of materials. Organs, or occasionally entire plants or animals, are dried or frozen for preservation and are termed crude drugs. They may be used medicinally in essentially this form, as in the case of the cardiac drug digitalis or the endocrine drug thyroid, or as sources of mixtures or of chemicals obtained by processes of extraction.

Mixtures obtained by exudation from living plants include such drugs as opium, turpentine, and acacia. Processes of extraction are required to obtain such mixtures as peppermint oil (steam distillation), podophyllum resin (percolation), and parathyroid extract (solution). For a discussion of classes of natural products with medically significant members of this type, see ESSENTIAL OILS; FAT AND OIL, EDIBLE; GUM; TERPENE; WAX, ANIMAL AND VEGETABLE.

Pure chemicals may be extracted from a crude drug (for example, the glycoside digitoxin from digitalis or the hormone insulin from pancreas) or from a mixture obtained by exudation (for example, the alkaloid morphine from [illegible]

n ext a t d mi ture (for ample tl e terp ne m nth l f m p pp m nt il) Fo d u n f tural pr d t l th t pe see ALKALOID GLY to DE HOR IONE

Vitam s a a l f n t al p odi t are ith n th p f ph rma gno y alil gh many re n w bt i d omme c lly by labo at ry syn thes In luded al o ar nt li t c and b l i l (um a c ne and d gn t b log c l pr d t) S ANTIBIOTIC VITA IIN

The g r l l ol gy of pharm g o y is largely d c ipt It i cl de the ta nom pos t n f the at ral ourc of th produ t the part of the pl t an mal yi ldi g the drug the c e t fic d mmo n m f the l l g ce the g o nd hi t l g c anat m c l s acte izati n of th pa t ed a d the prin p l f the prod t th health p fe n

Th h ch mi try f i f d ipti and xperi m nt l it lude the cl m al natur and pe ntag f th medi ally ign ficant n t tuent the mech n ms f bi ynthe of th n t tue t a d th r l f th t tue t n th n my of th pl t Inc a i g att t o i be n pa d to mechan m f b ynthe by th f ado t p c r f m dically act o llt nts r f ll w i th t p by t p Th fat n nd h m c l d nt f i of ne p t tially u f l pla t d m l c n i t t a e an mp rt nt a pect f b o hem al a h n pl macog y

Th ec n m pe t i l de th d ry and t dy f t al sou f r de d u a d th d at d l pme t of ult at d ur h f ll mp em t l th ld f ef l t t a d p t t f m d ally eful p pl nt f m th t ral n mi M thod f h rvesti g l i g i g th p ng t tm t t g p k g ng nd h pp ng ente nt th mm r f d ug

F a gl d g l ampl m th l f m r pp rm t il tl es ral p t a e fre t tl pa abl Th mm r l g we mu t kn th pec es f M th i ld ng mmer ally p f t l l q antit e f th es e t l oil a d of m tl l pe t g ld f m a pe e nd t n table f g with n tu al e emi s f th g w g pl t u h a pe h i u e m tl ds f xt i f th l a d f lat f th r e th t f p r r d f r pa kag t r g hipp g th r fi d d g S t fi td of th g n t f pec f M tha f ad m f t f pol nt) mm l mp rt n

Uses of materials Medi al u ht fly s th pe t p rh l t d g t ge t f t th t i th nt th m t m di a f ll nt e w p eem nll of n t al p od t t ll i l t il ed t Tw i th- t es h t tr l ut d ma y yn h t l m nth t d g t h mod rn ma i med l t ign fi nt n mb r f d d g a ll th d g f h n th ap r ers th so r f w l l d p fied m e tu l rm l D g tal d it gl e d th lk l l of g rt n l bell d n p n ll thy r d insuli a d poli myelit s vaccine are exam ples

Pharmace t al s a e ch efly in the p oduc ti n f p latable and t bl do age fo ms gums and mu ilage in emul ion nd pen ons starch and lact e in tablets sugar nd e t al oils in el rs oil a d wax s in o ntment Many natural produ ts of i ignifi ant or qu ti nable therapeu t c alue co tinue to be u ed in home remedies

U es in other health profess on include anti ptic p otecti es and local a e thetics u ed by de ti t od nt cide n eticides a d other p ti c des us d in th p ot cti n of the publ c health and a ar et of prophylactic and ther p uti ag ts u ed by eterinar an

A la ge numb r of natural prod cts of value in the he lth pr fe on a e u ed al o i co metology (e e t al ils gums fat and waxes) in the cul n ry arts (pice es ent al o l and condiments) and in d try (na al stores mucilag s fats and wax s)

The ole of a m dically acti e ch mi al produced d u ed by the an mal u gani m s u ually well u de tood Pl y ologic funct on within the rgan m and th r peuti us by m n are us ally lo ely elated a n th e of pep in thy o d r the ex ho mon

Corr p nd g knowl dg of m d cally ct e plant n t t ents alm t non tent Th ole f m nth l n th ec n my of M nth p perita of d t x in D git lis pu pu a of morph n in Pap ve somn f rum or of e e pin n Rauwolfia p t a s unknown Th o h the centur es h were manki d has d c v red that e ta n plant l e the sympt m f r cure certa dis ea With the d c ery of alkal id n the earl n net nth nt ry and of the oth majo cla f med lly act plant c n tituents the chem l re p ns ble f therapeuti a t ns ha been identified o by on b t not the f n ti n f the e hem l i the r e p ti e pl t ources

Types of materials Cla s f therapeut c ag nt ha e f q ently been d s vered by tudy f bio- ynthe i ed med i l hem cal M t s h la e fa t ha be n d elop d fr m ch m c l o g n lly k wn f om ude d ugs r from the e dat r e t acti The fi t n f f um ar t c and analg i d a e l t in a t q ti but ts p s t on n tl e m d al pra ti of th d y h b p imary f ver 000 y a s Mo ph w s mo g the fi t lk lo d t l i o- lated ha b n wid ly u ed fo m r th 150 a s and f m ts tudy has dev l p d a lass of an lges drug f wid ppli at n in med al p a t

An al g p tt rn h s g en tl mod n l es f h p ten v d ug and tr nqu liz r Th l d and g rau olfi aft r turi f u f lk med ne es nt ally f und t way nto n r fi med I p a tic the or ent St dy of n h m al d i at du g the 1930 and 1940 revealed the p esen f m y alk l ds ne of whi h r pine w s h wn to b an eff t a t h p rt n e ag nt Sub eq nt ther p utic u e f

reserpine and other rauwolfia products soon demonstrated the tranquilizing action. A large class of drugs having hypotensive action, tranquilizing effect, or both has been developed rapidly. Various species of the genus have been characterized morphologically, and intensive study has been undertaken of practical methods of culture.

A third major class of modern drugs of natural origin, the antibiotics, has been developed largely since the beginning of World War II. The prototype, penicillin, was discovered in part as a result of fortuitous accident, but the many other commercially available antibiotics have been developed as a result of carefully planned systematic search.

Not infrequently the clue that has led to collection and scientific investigation of a crude drug as a possible source of medically significant constituent has been use of the drug by uncivilized peoples for a nonmedical but to them desirable purpose, such as narcosis, or as a poison against wild animals or man. The use of opium as a narcotic by the laity undoubtedly preceded its medical use. Coca was chewed or sucked by the Indians of South America to increase endurance; was condemned by the Spanish who conquered the Incas but was eventually introduced into medical practice in Europe. Discovery of the local anesthetic action of the alkaloid cocaine led to the development of a new and important class of therapeutic agents, the local anesthetics.

A second native drug from South America, curare, was first used by the Indians as an arrow poison for killing wild animals used as food. The neuromuscular paralysis caused in game by the drug suggested therapeutic use as a muscular relaxant. Studies of the plants yielding crude curares revealed several species of two principal genera, *Strychnos* and *Chondodendron*, as the main sources. A number of crystalline alkaloids was isolated from crude curares; eventually the alkaloid tubocurarine was identified as having the therapeutic potentialities suggested by the paralyzing action of the native drug. The botanical source was established as *Chondodendron tomentosum*.

Comparable studies of the African arrow poisons inee and kombe have added ouabain and strophanthin to the class of cardioactive glycoside, of which digitoxin is the most widely used. The arrow poisons are prepared from African species of *Strophanthus* and are used by natives of both the eastern and western coasts.

The alkaloid physostigmine, also from an African poison and useful in the treatment of glaucoma, was discovered as a result of use of its plant source as a human poison in the trial by ordeal of those accused of offenses. The alkaloid is the toxic constituent of the seeds of *Physostigma venenosum*, which were fed to the accused. Toxic symptoms were taken as evidence of guilt; those who vomited the material were considered guiltless.

Synthetic materials. Development of synthetic drugs related chemically to the active constituent of a natural product has frequently followed investigation of primitive use of the natural product as drug or poison. The objective of such development is usually to produce a drug having fewer undesirable side effects while retaining the useful therapeutic action. Substitutes for morphine, reserpine, cocaine, tubocurarine, and physostigmine are among a host of synthetic drugs which accomplish the objective to a greater or less degree and whose discovery depended upon study of natural products.

Intermediates useful in the laboratory synthesis of drugs often exist as therapeutically inactive chemicals in natural products. Plants and animals biosynthesize many such compounds with chemical structures similar to but not identical with medicinally useful substances. A slight change in molecular configuration may yield a potent therapeutic agent. A simple example is pinene, a chemical abundant in turpentine oil and convertible by laboratory procedures into camphor. The resulting synthetic camphor is actually semisynthetic and possesses the therapeutic and most other properties of natural camphor.

An important class of natural intermediates are the steroids, widely distributed in both plants and animals. Some chemical variations are active physiologically and as drugs, for example, sex and adrenal cortical hormones. Natural sources, glands of domesticated animals used as food by man, are not available in quantities adequate to fulfill the drug needs for these products. Many plants contain steroids suitable as intermediates for sex hormones. Natural intermediates readily converted into adrenal cortical hormones are uncommon, and extensive search for such steroids has been made since the late 1940s. Field studies involve collection and identification of plants judged to be potentially good sources of steroids, preliminary extraction and determination of the presence or absence of these intermediates, and further collection, drying, and preserving of larger quantities of promising species.

Systematic screening of plants of reputed therapeutic value and indigenous to a country or other restricted geographic area is a costly and time-consuming procedure—a major reason it has been done for relatively few regions. Notwithstanding, such surveys give promise of uncovering new sources for known drugs, adding to knowledge of such little known drugs as hallucinogens and anticarcinogenic drugs, developing entirely new classes of therapeutic agents, and providing profitable natural sources of intermediates useful in drug synthesis. See ANTIMICROBIAL AGENTS; BIOCHEMISTRY; PATHOLOGY; PHARMACEUTICAL CHEMISTRY; PHARMACOLOGY; PHARMACY; PLANT PHYSIOLOGY; TRANQUILIZER.

[R. A. D.]

Bibliography: American Association of Colleges of Pharmacy, *Teachers Seminar on Pharmacognosy and Related Subjects*, 1953, 1959; E. P. Claus (ed.), *Gathercoal and Wirth Pharmacognosy*, 3d ed., 1956; R. Pratt and H. W. Youngken

Ph m og y 2d ed 1956 H W Youngk n *T t Bo k f Ph mac gno y* 6tl ed 1950

Pharmacology

The e f detect and measureme t of the ffect f dr gs o other ch m cal on b olog cal tem Th eff t of h m cals may be b nefic al (th apeut) r harmf l (t x c) whe admin s tered t ma oth mamm l ther l ng sys tem Th pu h m l or m xtu e m y be f atu l or gin (pl nt an mal or m neral) r may be nth ti ompo d

The br d ar a c ve ed may be nv me tly di v d d nt a numb r of cat g ies chem therapy th t of chem c l to de troy di gan sms l a b cte nd mold n n th h t phar m th r py the u e of d ug to re t or repl ce m l f n t t s t ssu e lls rg ns r nt g at d t pl a ma d nami s tud e on the m h a i m f cti of d g wh ch may uti li phy l g cal b h m al o ele tri al t ch n q es t l gy th t dy f the po o ou ef f t f h m al p h ph rma f gy the tudy f th effect f hem c l n th b ha r f man an mal bi hemi al pha macology the effects f h m al b h m al a t on i h ing sys tem an f th effect f thes sy t ms on the ch m c l th t th metal of m tr cture a t ty r lat n h p elati hip f b l g c l a t v tv t h m l tri t re and m le ula p ti s and l l ph rm c l g th t dy and e aluat n of th ffect f dr gs i man S CHEMOTHERAPY PATH OGY TOXI OLOGY

The h m al h h h e h fi l ff ct in ma (h t g fu t o beha r to- s d th n rm l t te l e i g p n d t o ng harmf f t d g g n m id ng n the di g f d a alled d th ch m c ls h h p odu nly harmf l eff cts a e alled po son All d m y be po s u l w t if ad m t ed in i g n gh am S Poi o It e f d m ni l p pe t f d that th ff t a n t ty th d n re d D t m t l th elati n hip d l n te th d pon e t Th r lat h p c n be u e l ll mma ed b th d qu d t p od ce a t d d ed ffect nd al t th l p f th n l n m f t t the ume l p n f th d q ed t p odu 50 f th ma i m l pon perm t mpa so f d ug ha g the am t f a t n Th ED_{50} (d e ff t th 50 le l) ll the ta d d ff ct d ed mpa th pot n f dr g h g th m t n t an b d t rm ed with ll p nt g l th m mal ffe t M em t f t a ma f t d by lethal ffect p m l the LD (l th l e 50) Th l a f t f d ug est mated t me n l th th pe t d whi h th t (t) (LD) t th ED_{50} Th h gl th t th t th dr g S EFFE TI E DO E 50 LETHAL DOSE 50

The n es ty to u e such terms a ED_{50} and LD_{50} whi h are a erag implies that ind viduals ha e b en f nd to d ff r in the mount f drug that each will requ e t produ e the d ired effect It is comm n k wle lge that vari t s indi iduals toler te w dely varying quant t es of ethyl al ohol Indi dual diffe e es c ur in the esp n e to all drug nd what may b an eff cti e d e in one p so may n t be ffe ti e in an the Individuals m y als diffe qualit t ely in the r resp n e to a dr g Dep nd ng p n the effe t under study place bo (p lls r oth r p epa at ons ntaining ta ch sugar and ol r ng matter but no pharmacolo i c lly a ti e age t) may al o produce a favorable re p n in s me ind id al The admin trati n of a pl cebo to a per on with hypert n on may ult in a tempo ary fall n bl od pre sure f r ex ample and n sever l t dies f ag nts u ed to r l e pai a many a 35% of the ndividuals tested obta ned r lief of pa n from the admin tra t n f the pl cebo Ob ervat ons u h as the e ha e pointed out the nece s ty of u ng a pla ebo on t ol o a p t control (a dr g f e tabli hed ti ity) in exp rim nt de i e l to eval ate a n w d u B cau th titt ide f the phy ician wh ad min ters a d ug may al influence the way pa t e ts re po d thi able cont lled b u f th do ble-bl nd t hnique th t is ne ther the in dividual n r th d cto k ws which s mple i drug and wh ch is pla ebo

Th f n mals h s l e n and is ab olutel s nti l to pr gres in pl rma l gy a d ther m d l i ne howe er d ff r t spe e m y d ff r ma k dly n t e r e p n to dr g both q a tita t ly and qual tati ely Drugs which pr duce da t on i o sp e may pr d c xc teme t in a oth r Fortu ately t chem al prod c s m la effe t in many p ci s includ g man Unf t nat ly all drugs f und ff t e i a im ls a e ct ff ct e i ma p um bly d e to d ffe en es in m t b l m e et on o to un c zed d ff r e e n th nat of th d e proce the phys log al me ha m f m i t n nc of the am functi n in different pec e Study of these diff r nce ha y elded mu h ba inf rmati on mech i m f cti s of d ug and n phy i lo l a d b hemi l d ff en s m ng spe Fu ture tud e m y be xp ted to nt ibute to the und st nd g of d dual d ffer nce within sp i S BIOASSAY PH ACEUTICAL CHEMISTRY PH R IACOG OSY PHARMACY PSYCHOPHARMACO- LOGI DRUGS

[C J K]

B bl g phy V A D ll (d) *Ph m c l gy n M d ci e* 2d d 1958 L S G odman and A G lma *Th Ph a l gi l B s* (*The ap u t cs* d ed 1955

Pharmacy

The h alth p ofe n co er ed with the d ov ry dev l p t pr d cti o and d trib ti n of d ug Drug a e bstanc s (th than d es) d t d gn prevent i or l eve tl mpt m f d F r lat n t l ly all ed

fields *see* MEDICINE; PHARMACEUTICAL CHEMISTRY; PHARMACOGNOSY; PHARMACOLOGY.

General pharmacy practice. This part of the profession is carried on in exclusive prescription pharmacies, semiprofessional pharmacies, and drug stores. It consists of compounding and dispensing drugs on order of the physician, dentist, or veterinarian; serving as consultant on drugs to the health professions and to the public; and selling other health supplies, such as antiseptics, bandages, and home remedies. Combination of nonprofessional with professional activities is customary in the United States, however, and is commonly termed retail pharmacy.

Hospital pharmacy. In addition to qualities characteristic of general pharmacy practice, hospital pharmacy includes special administrative features: provision of drugs for nursing stations; manufacturing of pharmaceutical preparations; teaching of nurses and medical and pharmacy interns; service to the hospital committee on pharmacy and therapeutics; and the preparation and revision of a hospital formulary. The hospital pharmacist may have charge of investigational drugs, radioactive pharmaceuticals, medical and surgical sterile supplies, and gaseous drugs for inhalation therapy.

Pharmaceutical research. One type of research is in pharmaceutical chemistry: synthetic if the objective is to produce new and improved drugs by laboratory procedures, and analytic if the objective is to provide improved methods of assay for quality control of pharmaceutical production. Research may be in product development aimed at provision of more palatable, stable, economical dosage forms. It may be on drugs from natural sources (pharmacognosy) or on the mode of action of drugs from any source (pharmacology). It draws heavily on investigations in organic chemistry, biochemistry, and microbiology.

Manufacturing pharmacy. The pharmaceutical industry is the mass production medium of drugs and suitable dosage forms. It produces some of its own raw materials but depends on the closely allied chemical industry for most of them. It sponsors and conducts extensive pharmaceutical research.

Pharmaceutical distribution and promotion are specialized activities within the pharmaceutical industry which are now commonly called pharmacy administration; this term also includes the commercial phase of retail pharmacy.

Pharmaceutical jurisprudence. This is a highly specialized area in pharmacy. General pharmacy practitioners and hospital pharmacists are subject to Federal and state laws on drugs and pharmacy practice. A board of pharmacy serves as the law enforcement agency and the examining and licensing body in each state; various Federal agencies administer the provisions of the several Federal laws governing pharmacy.

Other special fields of pharmacy include journalism, administration of national and state associations, provisions of modern drug standards.

Pharmaceutical education. From 1932 to 1960 the education of pharmacists consisted of collegiate studies for at least 4 years in basic science, mathematics, general education, and professional areas. In 1960 the minimal educational program was extended by 1 year to a total of 5 years of collegiate study. A flood of new and complex drugs, released at the rate of hundreds per year since the end of World War II, has made necessary for the pharmacist a strong background in the physical and biological sciences, highly specialized training in drugs, and the sociologic and humanistic understanding desirable in all professional people. [R.A.D.]

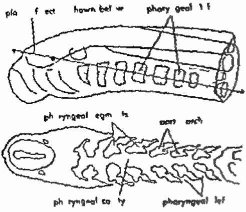
Bibliography: R. A. Deno, T. D. Rowe, and D. C. Brodie, *The Profession of Pharmacy*, 1959; Health News Institute, *Facts about Pharmacy and Pharmaceuticals*, 1958; E. W. Martin and E. F. Cook (eds.), *Remington's Practice of Pharmacy*, 1956.

Pharynx

A chamber at the oral end of the vertebrate alimentary canal, leading to the esophagus. Because of divergent specializations in the various classes of vertebrates, it cannot be described in general terms except at embryonic stages. In adult man it is divided anteriorly by the soft palate into a nasopharynx and an oropharynx, lying behind the tongue but anterior to the epiglottis; there is also a retropharyngeal compartment posterior to both epiglottis and soft palate. The nasopharynx receives the nasal passages and communicates with the two middle ears through auditory tubes. The retropharynx leads to the esophagus and to the larynx, and the paths of breathing and swallowing cross within it. In adult fishes the pharynx is not segregated from the mouth cavity but is pierced by a number of paired gill slits. *See* ESOPHAGUS; LARYNX.

Embryology. Shortly after the germ layers of the embryo are in place, the pharyngeal cavity appears as a simple enlargement of the anterior end of the endoderm tube. Its lateral or lateroventral walls promptly become thickened as a series of paired pillars, the pharyngeal segments (branchial arches or visceral arches), separated from their fellows by paired pouches which push outward from the endodermal lining of the cavity. These pharyngeal pouches are approached on each side by corresponding branchial grooves which push inward from the head ectoderm. The matching grooves and pouches may meet; their touching surfaces may then become thinned as closing plates, and they may actually break through as pharyngeal clefts. The mouth perforates into the pharyngeal cavity in a similar way anteroventrally. This embryonic appearance of the pharynx as an enlarged anterior gut chamber whose walls are marked by pouches, grooves, clefts, and intervening pillarlike segments is one of the few characteristics found in all members of the phylum.

The more primitive vertebrate embryos, such as those of lampreys and sharks, have up to seven or even more pairs of large open pharyngeal clefts of



Lamprey mbry s d w d h z t l t on f phary reg

fairly u f rm ize Embryos f rept l bird and mammal l o few r gm nt and l a p red iction f th more po t r n nes Al-o e eral of the la t pharyng al p uche fa l to break through a cleft Whe m t fi hes e eral po teri r clelt l ome enl ged nd the interven g egment be om equ pped with gill and val es d ri g d l pm nt, few e tiges l e ther pou h s or cleft em at adult tages f l nd n mal Ne erthe- less, in all ertebr tes the sol d t ues of the phs ry eal egm nt g ie ri e to numer s tr ctures f th he d and neck.

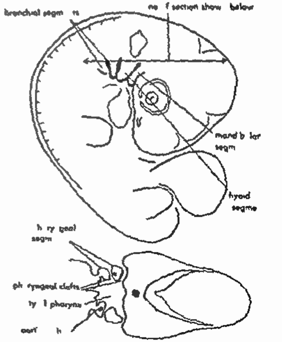
Ea h ph ryng al egm nt l th embr o i l ed b ectoderm (th l ture ep de m) on the out de a d b endod rm (th f t e m s m mbran) n the de Th mesod rm ncl ed betw en th e l y rs f h p ne r lateral plate *mg n* d d ff r nti tes chiefly nt mu cle and arterie (RESPIRA ORY SYS EM) I add t n t the con t tuents t gu f neu al t ell migrate d n t to the ph ryn l gm nt and d ff n t te the m k let l leme ts e ept in clo- t me fi hes *S* NEURAL CR ST

Pharyngeal derivatives Th fi t p of pha yng al gme ts, lled th m dib la egme ts l th m uth between th m a d th ir kele t n form g e ll p odu e th m ndibular art l g wh h a e the a f t rudim nt of the lowe jaw Th i mu le-f rm g ell d ff ntiate nt a d l gr p f m cl wh e p i ipal fu t on n ll gnath tome e teb ate s t n p th j w hut, an l t l g p wh ch upport the ton e l y f m ng a he t b tw n th b l es f the lower j All th m les a uppl ed by th motor d i of th t g m l nerv *Se* GNATHO TO MATA

The ec d p r re alled th hyo d m t They a j t po t r r to the m dibul g m nt u ually sep ated fr m them ter p a ily b Hyom d b la left Th y l ventr l t the a les on th de of th embry m h ad Th r k l t n f m n ll fo m mport nt pa ts of th t ngue upport and th mu l are u d i om rt b te lor p g the m uth f t ngue m pul t n f l s l e p on nd th r fu c t n The m t r d i n f th f cial nerve in n rvate the hy id gr p f mu les In higher vert l rate tl e hy mand l lar j uct s i ol ed in tl e fo mati n of tl e a dit ry tub and th mi l lle ear space

The th rd and all m re po teri r p it are called Lra l sl egm nt i e i fi hes tl y u all f rm g ll bearing ar l es the te d t he r pr ed s di per ed t th de el pme t f tl higher v rte- b ates The r kel t n f rming ll th r f rm a ucces i n of j inted r odl ke bones or cartilage f r th ipport f gill a in fi hes r j i the hyo l kelet n in t ngue upport and c r n ntral ventrally i th l ryn artilage a in terrestrial v rtel ates In f hes the m iscles ler1 ed fr m tl first bran l ial egment (th *third* n tl e *pharyng al* e es) are st i tly inn rvated l y the gl sophar n geal n rve and tl f all tl e rest if th gm t by indi idual *l r nches of the vag n rs* Tl ey f ti n f *manip ilat* n l th g ll and f r gr nding and wall ng food In l gh r verte- brates the lranch al egment be m less an l les di tinct d ring d vel pm nt nd the n rve s ipply wh le till de ed f om tl glossopharyng al and ag n rves i n t s clearly gm ntal in th tr ted mu les tl em el es l ec m arr nged in a m re r les c nt nu pharynx r n tri t r heet or ngregate in the l ryngeal cartil ges rving new me han ms f swall wi g and und pr d c ti n *Se* SPEE H

Histology The phary x l in g n ral l ned l simpl m c u m mi rane ba ked by f l r u c n necti e ti ues a d a d ul l lay of tristed mi le In bony fi hes it kel tal arches m y be tl kl studded w th mple te th or may e n be devel



Ch ck mbry s de ew a d ho t l se tio f ph ry x g

fields *see* MEDICINE PHARMACEUTICAL CHEMISTRY PHARMACOGNOSY PHARMACOLOGY

General pharmacy practice This part of the profession is carried on in exclusive prescription pharmacies, semiprofessional pharmacies and drug stores. It consists of compounding and dispensing drugs on order of the physician, dentist or veterinarian, serving as consultant on drugs to the health professions and to the public, and selling other health supplies such as antiseptics, bandages and home remedies. Combination of nonprofessional with professional activities is customary in the United States, however, and is commonly termed retail pharmacy.

Hospital pharmacy In addition to qualities characteristic of general pharmacy practice, hospital pharmacy includes special administrative features, provision of drugs for nursing stations, manufacturing of pharmaceutical preparations, teaching of nurses and medical and pharmacy interns, service to the hospital committee on pharmacy and therapeutics, and the preparation and revision of a hospital formulary. The hospital pharmacist may have charge of investigational drugs, radioactive pharmaceuticals, medical and surgical sterile supplies, and gaseous drugs for inhalation therapy.

Pharmaceutical research One type of research is in pharmaceutical chemistry, synthetic if the objective is to produce new and improved drugs by laboratory procedures, and analytic if the objective is to provide improved methods of assay for quality control of pharmaceutical production. Research may be in product development aimed at provision of more palatable, stable, economical dosage forms. It may be on drugs from natural sources (pharmacognosy) or on the mode of action of drugs from any source (pharmacology). It draws heavily on investigations in organic chemistry, biochemistry, and microbiology.

Manufacturing pharmacy The pharmaceutical industry is the mass production medium of drugs and suitable dosage forms. It produces some of its own raw materials but depends on the closely allied chemical industry for most of them. It sponsors and conducts extensive pharmaceutical research.

Pharmaceutical distribution and promotion are specialized activities within the pharmaceutical industry which are now commonly called pharmacy administration; this term also includes the commercial phases of retail pharmacy.

Pharmaceutical jurisprudence This is a highly specialized area in pharmacy. General pharmacy practitioners and hospital pharmacists are subject to Federal and state laws on drugs and pharmacy practice. A board of pharmacy serves as the law enforcement agency and the examining and licensing body in each state. Various Federal agencies administer the provisions of the Federal Federal laws governing pharmacy.

Other special fields of pharmacy include journalism, administration of national and state associations, provisions of modern drug standards.

Pharmaceutical education From 1932 to 1960 the education of pharmacists consisted of collegiate studies for at least 4 years in basic science, mathematics, general education, and professional areas. In 1960 the minimal educational program was extended by 1 year to a total of 5 years of collegiate study. A flood of new and complex drugs released at the rate of hundreds per year since the end of World War II has made necessary for the pharmacist a strong background in the physical and biological sciences, highly specialized training in drugs, and the sociologic and humanistic understanding desirable in all professional people. [R A D]

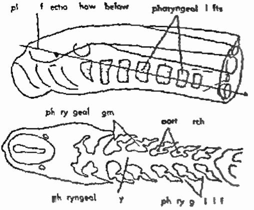
Bibliography R A Deno, T D Rowe, and D C Brodie, *The Profession of Pharmacy*, 1959; Health News Institute, *Facts about Pharmacy and Pharmaceuticals*, 1958; E W Martin and E F Cook (eds), *Remington's Practice of Pharmacy*, 1956.

Pharynx

A chamber at the oral end of the vertebrate alimentary canal, leading to the esophagus. Because of divergent specializations in the various classes of vertebrates, it cannot be described in general terms except at embryonic stages. In adult man it is divided anteriorly by the soft palate into a nasopharynx and an oropharynx lying behind the tongue but anterior to the epiglottis; there is also a retropharyngeal compartment posterior to both epiglottis and soft palate. The nasopharynx receives the nasal passages and communicates with the two middle ears through auditory tubes. The retropharynx leads to the esophagus and to the larynx, and the paths of breathing and swallowing cross within it. In adult fishes the pharynx is not segregated from the mouth cavity but is pierced by a number of paired gill slits. *See* ESOPHAGUS; LARYNX.

Embryology Shortly after the germ layers of the embryo are in place, the pharyngeal cavity appears as a simple enlargement of the anterior end of the endoderm tube. Its lateral or lateroventral walls promptly become thickened as a series of paired pillars, the pharyngeal segments (branchial arches or visceral arches), separated from their fellows by paired pouches which push outward from the endodermal lining of the cavity. These pharyngeal pouches are approached on each side by corresponding branchial grooves which push inward from the head ectoderm. The matching grooves and pouches may meet; their touching surfaces may then become thinned as closing plates, and they may actually break through as pharyngeal clefts. The mouth perforates into the pharyngeal cavity in a similar way anteroventrally. This embryonic appearance of the pharynx as an enlarged anterior gut chamber whose walls are marked by pouches, grooves, clefts, and intervening pillarlike segments is one of the few characteristics found in all members of the phylum.

The more primitive vertebrate embryos, such as those of lampreys and sharks, have up to seven or even more pairs of large open pharyngeal [illegible]



L mp y mbry de w o d h o t l cto f ph ry g

fa ly nif m Emb y f ptil s b rd a d mamm ls li w few r gment a d harp r d ct on f th m re p t or ne Al-o e eral f th l t pha yn al p uche f l t break th ough a cleft Wh a t m t fi hes e eral p tern r lefts be om n larged n d the nterven g gments be om eq pp d w th g lls and l e dur ng d el pme t, few e ti s of eithe pouche el ft em at adult t ges of land a im ls N rthe- l all e teb tes th sclid t u f the ph yng l gm ts g v e to ume s at ct res of the h d d ne k

E h ph ry geal egm nt of the embryo s l ned by t d m (the fut e p d rm s) on the t de a d by doderm (th f t r muc u membrane) n th n d Th me od rm e clo ed b tw en thes la er f hyp m l t ral pl t gin and d ff r nt at ch efl t m scle a d art ri (Resp r tory yst m) I dd t t the c tt t t gue f n u l c e t e lls mig te d wn to th ph ry g al gme t and differ t t th e t kel t l el ment x pt i yclo- st m fi hes S Neural crest

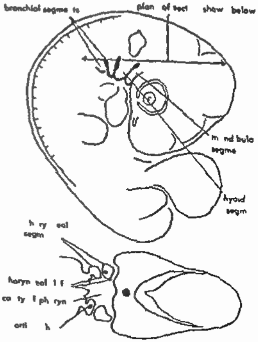
Pharyngeal derivatives The fi t p f ph ry g f egm nts, ll d th ma d b la egm nts, l th m th between th m nd ther kele- t n f rm ng lls p oduce th m ndib l rt l es, wh h e th l st r d m nt f th low r j w Th m le f rm ng lls d ffe e t t to a d l g p f m les wh e p n ipal f n t n ll g ath t me ertebrates to p the j w h t a d tr l gr up wh h pp rt th t ngu by f rm g h t b twee the l l s f th low j w All th m cle ar ppl ed by th m t d i of th tr g m n l rv S e G athosto m t

The ec d p ir a e lled th hy d s gm t Th y r j t post t th m d b l e m t u u lly p r ted f m th m t p a ly by h m d b l l ft They l t l t th r les o th id of th embry n he d Th r k l t f m g ll f rm mp rta t p t f th t n upp rt nd th m les d n me rtebr tes fo op n ng th m th f t g m n p lat f f l xpr nd ther fu

ti n The m t r di i n f the facial ner e in n rvates the hyoid gr u f m le In higher ertebrate the hyomandib l r p ch i in l ed in the f rmat n of the aud tory t be and th m ddle ear pace

The third and all m re p t ri r p ir ar called bran hi l egme t i e in f hes they u ally f rm g ll l a i g arches th y tend t be r j r ed r d p rsed in th dev lopm nt of th higher rte- b ate The r kel t n f rming e ll ent r f rm suc n of j inted rodlike bone r cartil ges for the s pport of gill a n fi hes, r j n th h id kelet n t ng i pp rt and n n ntrate v ntrally in th larynx cartilag s in t rrestri l vert b ates M fi l es the mu l l r ed fr m th fi t branchi l egment (th thir l in th e pharyng al ent) are t ictly i ervated by th gl ph r n geal nerv and th f all th r t f th segm t by nd id al bran h s of the vagu n rve Th i funct n f manip lat f th gill d f r gri d ng and wallowing food In h gher erte brates the bra chial egm nt l ec m l an l l s d ti t d ri g de l pment a d the n rve p j ly wh le till d ri ed fr m th gl sopharyng al and vag erve i n t el arly egmental m e th triated mu cl th m el n l ec me arr ng d i a m re r les co ti u us pharynx-c n trict r l t r congregate i the l ryng al cartil ges rvi g new me h n m f swall w g and ou d production S Speech

Histology Th ph ryn i in g neral lined by a mpl muc membra e l k d by fil us c n ne ti e t ue and a d ul l lay f triated m s cl l bo y fi h its kel tal rches m y l thi kly studded w th mple t th r may ev l dev l



Ch k mbry d w d ho t l ct f ph ry g

oped into grinding or crushing plates. Terrestrial vertebrates show simple tubular glands emptying usually in great numbers through the mucous membrane and tonsillar collections of lymphoid tissue in the submucosa. See TONSIL.

Gross derivatives. Elaborate gill pouches are developed in all aquatic groups and subject to many special adaptations. They differ sharply in design in lampreys, hagfishes, cartilaginous fishes, and the bony fishes. A median ventral evagination from the posterior end of the pharynx gives rise to the entire respiratory system of the land vertebrates, including lungs, larynx, and trachea. A similar but often dorsal evagination, usually from the pharynx-esophagus boundary, gives rise to the air bladder in bony fishes. See RESPIRATORY SYSTEM; SWIM BLADDER.

The epithelium of the pharyngeal pouches and of the pharynx floor produces a constellation of endocrine glands and other structures. See PARATHYROID GLAND; THYMUS GLAND; THYROID GLAND; ULTIMOBRANCHIAL BODIES. [W.W.B.]

Bibliography. L. B. Arey, *Developmental Anatomy*, 6th ed., 1954; A. S. Romer, *The Vertebrate Body*, 2d ed., 1955.

Pharynx disorders

These include the more common congenital defects, inflammation, tumors, and nervous disorders which affect the pharynx.

Congenital defects commonly seen are malformed or split uvulae or cleft palates and extension of a cleft palate backward to the pharyngeal region. See HARELIP.

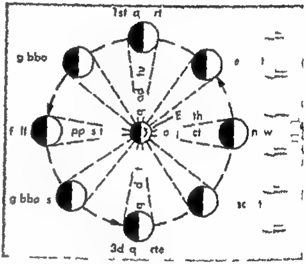
Inflammations may be local or part of a systemic involvement. Acute pharyngitis may be caused by almost any irritant and typically does not involve an infection by a microorganism. Acute follicular pharyngitis is caused by infectious bacteria, usually streptococci; it is also called septic sore throat. Acute tonsillitis involves the masses of lymphoid tissue found in the back of the pharynx. The tonsils may also be the seat of peritonsillar abscesses. All of the above inflammations may persist as subacute or chronic diseases, but usually the more prolonged forms occur as a result of repeated attacks or low-grade persistent infection. See STREPTOCOCCUS.

The most common benign tumor of this region is the papilloma; hemangioma, fibroma, and other less common nonmalignant growths are also found here. The malignant tumors of the pharynx include several varieties of carcinoma and sarcoma, particularly lymphosarcomas in children. See ONCOLOGY.

Nervous disorders seen not infrequently are paresthesias (abnormal sensation) and hyperesthesia (increased sensation). Neuralgia of the glossopharyngeal nerve is marked by severe pain in the neck, ear, jaw region. Motor disorders which affect swallowing may originate from local irritations or from central nervous system disease, as in the case of rabies. See PHARYNX; SOMESTHESIS. [E.G.S.T.]

Phase (astronomy)

In astronomy, the changing appearance of the Moon, inner planets, and Mars due to the angular difference between the incident light from the Sun and the viewing direction of the observer. Phases of the Moon are a familiar sight. During a lunar month (29.53 Earth days), the Moon completes a cycle of appearances or phases: dark of the Moon or new Moon during which the Moon is nearer the Sun than is the Earth; crescent until first quarter (about a week after new Moon); half an illuminated disk; the Moon continues to wax, being gibbous until it is full; it then wanes through third quarter and completes the cycle as illustrated. A



View from Earth of Moon differently illuminated as Moon travels around Earth.

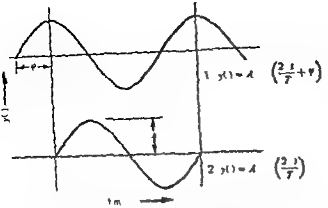
solar eclipse by the Moon can occur only at dark of the Moon; a lunar eclipse when the Earth's shadow falls on the Moon can occur only at full Moon.

Mercury and Venus show phases like those of the Moon. Mars varies in appearance from full to gibbous. The more remote planets are so far from Earth and Sun that they are viewed from substantially the same angle as that from which they are illuminated and thus show no phase change. [C.P.K.]

Phase (periodic phenomena)

The fractional part of a period through which the time variable of a periodic quantity (alternating electric current, vibration) has moved, as measured at any point in time from an arbitrary time origin. In the case of a sinusoidally varying quantity, the time origin is usually assumed to be the last point at which the quantity passed through a zero position from a negative to a positive direction. It is customary to choose the origin so that the fractional part of the period is less than unity.

In comparing the phase relationships at a given instant between two time-varying quantities, the



An ill t at n of th me ng of ph s f dal w e The d ffe e ce 1 ph b twe wo e 1 a d 2 1 n d is lled the ph e a gl F ach w e A is the ampl tud d T i th i d

ph f o e 1 n ally a sum d to be z ro and th ph f the oth 1 describ d with re pe t t th fir t a th fractional pa t of a pe i d th ough hi h th ec nd qua t ty m st vary t a h eve a ze o of its n (s e Ilu t at n) I th ca e the fr ti nal p rt f the pe d s u ally e pre ed i te ms f ang l m a u e with one pe od being eq l t 360 2– r d an Thu tw s ne w f g n fr qu n y a e sa d t be 90 r $\pi/2$ t of pha e whe th nd m t be di placed in t me w th re pect t th fir t by ¼ p r od in ord r l t t h e v l See SINE WAVE see al o PHASE AN LE EASUREMENT [W.J C]

Phase inverter

A r u t l g th p ma y fun t on l hanging th pha of s g l by 180 The ph s s rt r i m t c mmo ly empl y d as the p t stage f r a pu h p ll mpl fi r The f e the ph n rter m t pply two ltag f qu l mag t de a d 180 ph n d ffe A r ety f rcui t e a l bl f th pha in e 1 Th e r t u ed 1 ny g e e dep ds pon h f t rs a the ov all g of the ph e ert nd p h p ll mpl fie the p l l eq r m t th t th np t t th p p ampl fi m y req p we pa e equ m nts d o t S PU H PULL AMPLIFIER

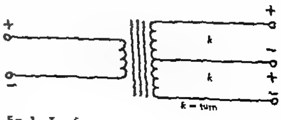
The o all fidel ty f a ph in e t r nd p h p ll mpl f r b d l ff t d by im p pe de gn f th ph n rt The p n pal p obl m i th t the f q e y e r n e of n i p t ch l t th pu h p ll ampl fer ma be d ff rent from th f q n y e p f the otl r han el Th popul ph e s r u t r pable f pe f m g th j b ly aft e ful el t n f u tube nd th mp nents S me ph r it n pe f m i v r n at nly o e f q n y r th r fr q n d t rt n s i t o- d d b of n q l f q n y e p n h a t t

Transformer inverter Th s mpl t f rm f ph e erte r t s t n f rm w th c te t pped nd ry (F g 1) C ful d n f the t n l m th t the nd y lt g ar q l Th t a f rm f rm g d t h n th n r m t pply powe to the g ds of the pu l pull ampl f r The turn ratt can be adju ted fo m ximum p w r tran fer S TRAN FORMER

The t an f rmer inve t r ha eral di ad a tage It u ually co ts m re an l cupies more pac than a c m t l circ it Furtl rm re me mean mu t l e fo and to comp n ate f r th fr quency re pon e f the tran f rm r whi h may n t be a un f rm as that whi h can be l tained f om ac um t b cir u t

Paraphase amplifiers A acu im tube amplifi r that p ide tw eq al utp t gnal 180 ut f pha e i all d a p raph a e ampl f r If c upl ng capacit r can be mitted tl imple t para l a ampl fier ll trated in Fig ? The am urrent fl w tl ugh R and R an l tl r f re if R_L and R_K are eq al th c tp t v ltages fr m th plate and th athode mu t be equal n mag it d an l 180 ut of pha n The ga n f the ci uit i l th n unity which i e f ctor th t limits it ap- pl ab l ty A sec nd mporta t fact r is that the add t f u l n capacit an l g d l ak re- i t r nece ary when the cir u t i coupled t tl p h p ll tage s the pha in er t l e other th n id al er the f eq e y range of ex p ct d ope at n

A pa apha e amplifier for whi h th gain is gr ater than u ty i illu t ated in Fig 3 In the m dfrequ ncy range wher the rea tance f the ipl ng ap c t rs i negligil le the ga n f the mpl fie ct n i v l i g T s $-A_m$ wh r the m nu gn ind te 180 pha e hift If $R_2/(R+R)$ eq al $1/A_m$ th s gnal at the g d f T w ll b — If th midfrequen y ga n of the mpl fie s ti n olving T s al $-A_m$ then $= -A_m$ and $e = A_m$



Fg ? T f m ph ert

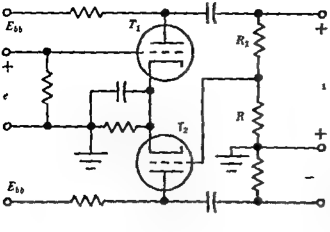


Fig 2 Single-tube inverter

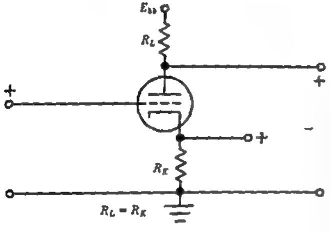


Fig 3 Two-tube phase inverter

In general $e_1 = -Ae$ and $e_2 = R_2/(R_1 + R_2)A^2e$ where A is the gain of the stage This gain is frequency dependent and therefore the phase shift varies with frequency Because e_2 is a function of the square of the gain the phase shift of e_2 will be twice as large at any frequency as will the phase shift of e_1 The two voltages are then not 180 out of phase and distortion will be introduced

Numerous variations of the above two tube paraphase amplifier are possible The two-tube circuit can be quite compact because one twin triode handles the tube requirements

If the phase inverter circuit is to produce two voltages 180 out of phase the equivalent circuit governing the behavior of the two output voltages must be identical The midfrequency gain of each must be identical and the phase shift functions must be identical (which was not true in this circuit) The phase shift requirements are often compromised in the interests of simplicity of the final circuit and freedom from critical adjustments of key circuit parameters [H F K]

Phase meter

An instrument for the measurement of electrical phase angle It is sometimes called the crossed coil meter or the Tuma phase meter and is the basic element of power factor meters and synchroscopes When used for power factor indication it contains two movable coils A and B on a common shaft as shown in the illustration The two coils move as a unit, the angle β between them remaining fixed. There is no restraining spring acting on the shaft and the system will turn as long as currents produce an average nonzero torque

The meter contains a fixed coil C which carries the load current The fixed coil is made in two sections so that its magnetic field will be nearly uniform in the neighborhood of the movable coil

The instantaneous force induced on coil A is proportional to the product of the instantaneous currents in coils A and C and to the sine of the angle between the planes of A and C. If the currents in A and C are sine-wave currents with phase displacement θ the average torque T is proportional to

$$(I\ \sin\omega t)[I\ \sin(\omega t + \theta)]\cos\alpha$$

or

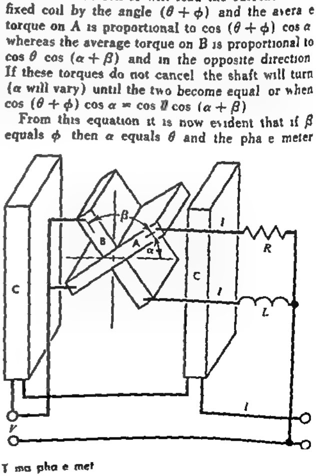
$$T = I\,I\ \cos\theta\cos\alpha$$

The movable coil A is placed in a resistive circuit so that its current I is in phase with the voltage V The other movable coil B is placed in an inductive circuit so that its current lags the voltage by approximately 90

In actual construction the circuit of coil A cannot be made noninductive and the circuit of coil B cannot be made nonresistive Therefore the phase angle between the currents in coils A and B is less than 90 The phase meter is constructed to take this into account.

If the current in coil B leads the current in fixed coil C by the angle θ and the current in coil B lags the current in coil A by the angle ϕ then the current in coil A will lead the current in the fixed coil by the angle $(\theta + \phi)$ and the average torque on A is proportional to $\cos(\theta + \phi)\cos\alpha$ whereas the average torque on B is proportional to $\cos\theta\cos(\alpha + \beta)$ and in the opposite direction If these torques do not cancel the shaft will turn (α will vary) until the two become equal or when $\cos(\theta + \phi)\cos\alpha = \cos\theta\cos(\alpha + \beta)$

From this equation it is now evident that if β equals ϕ then α equals θ and the phase meter



Tuma phase meter

d c t s d tly th pha e angl b tween the u ces upply ng coil C nd the c o ed c l A ch n e of 5 n the phase angle w ll produce a d fle ti n f 5 on th pha meter *See* PHASE ANGLE MEASUREMENT POWER FACTOR METER [H SO]

Bibliography F A Laws *Electrical M s e m ts* 2d ed 1938 M B Stout *Bas c Electrical M a ur m nts* 19 0

Phase modulation

A spec l k d f angle mod lat on in which the ln tly in r ng angle of a e-w ve carr er h s dd d t it a pl se angle that is p oporti nal t the ta taneous v lue of the modulati g wa e (m s- g to b mmun cated) Pha e modulati n (PM) i hem f r impres i g the me sag to b com mun ated pon a high freq e y e-wa e ca r e Th e d re t p opo t onal ty betwe n the me age to be commu cated d tl pha e varia ti n impa t d to tl mod l ted wa p opagated to th ece Fo ba ncept h al t rm d suppl me tary nformatio ee MODULATION S e ls ANGLE MODULATION

Advantages and applications L ke otl r forms of le m dulati n PM educes n s at the c t of tra b d dth occ pan y t an mits n t nt er g gn l p w r t n m t tant peak po e wh ch s qu l to tw ce the rage s gn l p a d ha han el grabbi g prope ty wh by if t o gnal a h th PM detector the l l i ccepted t the r ex l io f th sm ll

Imp tant appl ati n in lude erta n typ of t l gr ph t l m t ng d d t pr ce ing s- t m PM u ed rta m wa d relay y tem some f whi h arry teleph ne c e s ti n a d tel p gr m m lt u ly PM tech q e r d n m ny type of m ing d ntr l y tem

The h p l m tat on f rang f ha n l gr b- b gl e p ally mp ta t f ome erv e T p l xampl u i g PM n lud m b le and fi d d y t m f p l a tw y a d m lt y ppl t

Noise response of PM Noi e app a ng i th o tp t f n a gl m dulat det t d p nd up n th k d f gl m d lati n oth fa t b q l Wh n th n d tu b n h s th h a t t of t n no s the g e p i th outp t f a PM d t t s un f ml d t but d with e p t t f q y *S e* NOISE ELECTRICAL U d th m c nd t th d t b t f r t m qu re o e c nt n th tp t f f qu y m d l t n (FM) d t t d t b t n t ng l e rly w th f e q Oth k ds f a gl mod l t n ar h t d by th k d f e p t a N m lly th k d f l m d l t ed wo ll b that g g th b t g l to- t at *See* FREQUENCY MODULATION

Fundamental properties of PM I ta ta o h e t mply d e ces r ly ac m p ed by u qu fy l t d t t f q ncy va iati n and con ers ly Al gi en one it is po ible t repr duc the other

For example i PM tl e in tantaneou pha e ari t ns impart d t the mod ulated wa e are directly proportional t the modulating wav Tl e r ulting variation in in tantaneo frequency ar howe er dire tly proporti nal t tl e tim deri a tive of tl e modulati g wave

S m larly in FM th in tantaneo freq i ncy f the modulated wave i linearl pr porti nal t th modulating wave H we er th re ulting ariati in in tant ne i s pha e are directly p porti nal to tl e time integr l of the mod ulating wa e

Actually PM a d FM a e n t e tially liffer ent A ure it who e utput l s ver ly prop r ti nal t fr qu n y (zer freq ency pted) pr ced ng a pha e mod lat r cons rt PM t FM and following an FM d t tor r n ert fr q n y to pha e detection Similarly a circuit wh out put is *directly proportional* t fr qu ncy f e frequ ncy e pted) pre ed ng a freq ency modu lat ons rts FM t PM and f llows g a FM de te t r c n ert pha e to *frequency* d t ctio

Angle modulation ma ifest it lf by tl zer of the *angle modul ted* wa e Tl ese z r s are tl e x ct n ta t f time that the angl modul ted wave pas es through *ze* Th *r tically* g the z r s it i p bl t determi e f all alue l time the i t ntaneous *frequency* deviati ns f om the fi ed f eq ency of the *unmodul ted* arri and al the in tant neous ph e deviati n c rre pond g to th i tantane s fr q n y deviati n In th r w rd the *zeros* whi h r n th ng m re than a di t ibut on f p ints al ng the tim a i un m b gu u ly id nt fy th original mes ge

Wh n detect ng an a gle-mod lat d wa e per turbed by no n gn fi ant informat n m t be ign red b a e nly by thi mea an the full no e ad nt ge f angle m dul tion l e realized The l mite i a on entional FM detect ign res n n ig fi nt inf rm t by mpl tely d tr y ing the w ef rm f th r ei ed wave lea ing ly the er *S e* PHASE MODULATION DETECTOR PHASE MODULATOR [H S BL.]

Bibliography S C ldman *F q ency An lys s M dul tio and N ise* 1948

Phase modulator

An elect c c cuit that c u s the pha e a gle f the modul ted wa e to vary (with pe t to th u m dulat d arr) in acc rda e w th th modu lat on ignal Ph m dul t are mmonly ed n f eq ncy mod l t n tr m tter i which a pha e-modulat d wa e s lt ed int fr q ency m dulated w by frequ n y mult pl at n M ny m th ds for the g r t n of pha e-mod l ted w ve are k wn Th e of the m ommonly used e e de b d in this art le *See* MODULATION PHASE MODULATION

Phase shift circuit Th principl f perat o of a mpl ph m d l t r t i h w in tl block d g m f F g 1 R f ing t F g la the ca e w s g er te l by o ll t r wh ch

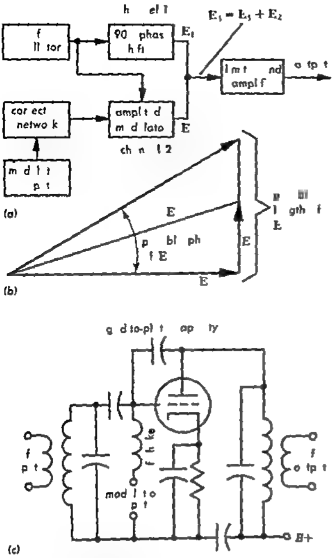


Fig. 1. A method for producing phase modulation. (a) Block diagram showing the principle of operation. (b) Vector diagram showing the combination of voltages. (c) A circuit which performs the necessary function except limiting, to be carried out [illegible] tube.

tant. The signal is passed through two channels 1 and 2. In channel 1 the signal is shifted 90° in phase and in channel 2 the signal is amplitude modulated. If a frequency modulated wave is desired the modulating voltage is first passed through a correcting network in which the output is inversely proportional to frequency. The output of channel 1 and 2 are then combined and passed through the limiter stage to remove the residual amplitude modulation. The action of the circuit is shown in the vector diagram in Fig. 1b. Here the vector E_1 remains constant in amplitude and the vector E_2 corresponds to the magnitude of the unmodulated signal. The magnitude of vector E_2 can be changed from zero to twice its normal value as it experiences amplitude modulation. Thus it can be seen that the resultant vector E_3 will vary in phase in accordance with the modulating signal. In practice a phase shift of approximately ±15° and linear [illegible] obtained in this manner while a nearly constant proportionality is maintained between the modulating voltage and the phase of the output signal.

A simple circuit that permits the generation of the phase modulated wave in this manner is shown in Fig. 1c. In this particular form a control grid modulated amplifier is used with sufficiently low gain to avoid the oscillation which could otherwise occur as a result of the feedback through the grid plate capacity. In this case the action of channel 1 occurs because of the direct transmission of the signal from the rf input to the output through the grid plate capacity, suffering a 90° phase shift in the process. The output of channel 2 is delivered to the output circuit as a consequence of the plate current and the normal grid modulation of the amplifier.

Armstrong circuit. Another method of obtaining phase modulated (or frequency modulated) wave employs the Armstrong system shown in Fig. 2, which is a modification of the elementary phase-shift circuit described above. The carrier oscillator supplies two channels. The first undergoes a 90° phase shift as before. The second enters an amplitude modulation balanced modulator in the output of which the carrier is suppressed. Upon recombination the resultant phase modulated wave is obtained and has the advantage that the modulation index can be approximately twice as great as

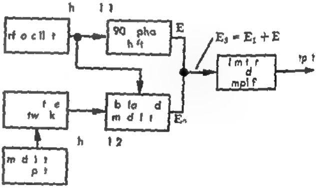


Fig. 2. Block diagram of an Armstrong system of phase (or frequency) modulator.

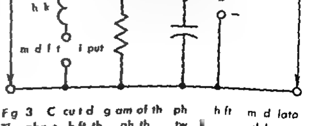
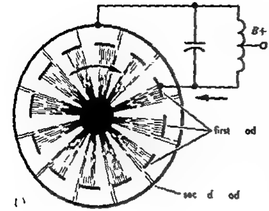
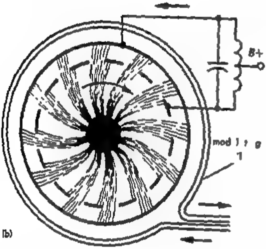


Fig. 3. Circuit diagram of the phase-shift modulator. The phase shift through the two [illegible] d by [illegible] the magnitude of the reactance [illegible] presented by the reactance tube.





Fg 4 D g m ll t t g th n pl f op t f th ph t t b ( ) Th t t g l t b t f m t l h d (h w bl k) (b) B d g f th l t m by f m g t fi ld ppl d by th m d l t g l d d the f le t t th o d d (F m R Adl A w yst m f f q y m d l t P IRE 35(1) 1947)

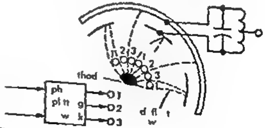
n th mpl t m d l d p t ly A pl a hift f ± 0 an l obt d w th g d l n ty

Phase shifter modulator A th p bl w y f d ng pl mod l t empl y a ta e t b th h ft t wl h n f the t ne l m t a d m g t f ele t all w th th l f th m d l t lt ge A l m nt it tl pl h ft p d d l a ang g tl t th t t b t t a ble ta m l t th t t b m d l t (Fr qu y d p d th t f tl ta f th p t r C t tl t p nt d f m pl t t tl d f tl t e t l W th p r l d d m d l t t p ll t lta n l l n m l l t n p to pha h ft f pp m t l ±60 Tl p rt l r d a t g f th pl a h fter typ f m d l t n that the ma m m m lulat n index an l e in re l and f nt l ly a cading a n mb r f mila pl a e hifter m dulat r

Phasitron I tl tem f pl a m lulati n th pl a hift of th arr r l tained l m a f a p ial l ctr n t l th pl a tr n Th prin cipal d ff ulty with n mal pl a e m d lat r i a r lt f tl elat ely mall am nt f pha hift th t an l e pr du ed with t ntr l ang n nl n arit and the re ulta t l rg am t f fr y m lt pl t which i all need l Th lff c lty alle i ted t a larg d g l y mean f th pha itr n i wl h pl a wing f a m l a ±200 an l e l t n l w tl l w d t rti n

Tl e pr ple f p at n f the pl tr n t l e can l xpla d w tl tl a l (Fig 4 S p th t n electr tr am p d ed t tl l rm f wheel p ke fr m a c ntral atl l wl l tl l tron m utwa d l ng ra l al lin an l r tat wit t n f m sel t Fig r 4 l w tl at the el tr n l eam alt rnati el w ll l inte pted l y the fir t a de r mitted t p t tl ec d an d Tl t ned circ t n ected l tw n tle tw a ode t tl ref r cited at a c n tant f qu cy qual t th pe d f r tati n f th lectr n p ke l y th gm nt d fr t an d If a m gnetic fi ld i appl d parallel t tl a f tl atl l th le t n l m a l fl t l a l wn F g 4b nd at th nd od e th el r l ter tl n rmal dep nd ng n tl e d ect n f tle m gnet f ld Tl e a l t ed l y tl m gn t field rre p n l t tl w tl f ne m t f the fir t an d t tl t tl ec n l od e t t ad an ed in pl l 180 Tl m nt f pha e h ft that n be l t ed lef d p the magn t field prod ed l y tl m l lat g ignal

In tl pl t n tl tat g l t t ke a p duced l b o nd g the atl de l a t el ge f d t t wl h tl pl ltage den d fr m a tal c ll t r a ppl ed A p ible ar ang m f r l tr l wn in Fig 5 If ll th w re mb ed l a e c n t d t geth r a d all n mb r a d ll 3 nd the tl r t ted f m a thr pha e ltag urce ro-



Fg 5 A g m t f d ff t w e th ty f th th d f th ph t wh h p m t t f t g l t n be m Th ph p t t l ppl d t the th t f w (F m R Adl A w y t m ff q y m d l t P IRE 35(1) 1947)

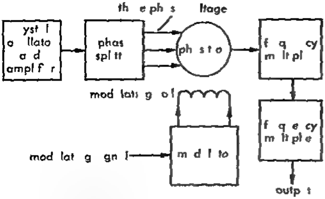


Fig 6 Block diagram indicating the method of producing frequency modulation by employing the phasitron tube

tating electron stream can be produced This can be seen by imagining that a set of wires numbered 1 are positive whereas 2 and 3 are negative this causes most of the electron current to be emitted in the direction of the wire numbered 1 thus causing the spoke to form The field along the squirrel cage rotates in a manner similar to that in a synchronous motor

Figure 6 shows the block diagram of a frequency modulated transmitter using a phasitron tube A crystal oscillator operating at some low radio frequency supplies a voltage to the network consisting of inductances and capacitors from which three voltages 120° apart are derived The introduction of this three phase voltage to the squirrel cage elements of the phasitron creates the rotating electron beam The rf output from the phasitron is introduced into subsequent frequency multiplier stages The phase of the output carrier is shifted by means of the signal derived from a modulator amplifier as indicated [E L G]

Bibliography R Adler A new system of frequency modulation *Proc IRE* vol 35(1) 25–31 1947 F M Bailey and H P Thomas Phasitron FM transmitter *Electronics* 19(10) 108–112 1946 H S Black *Modulation Theory* 1953

Phase velocity

The velocity of propagation of a simple harmonic wave It describes the distance required in unit time for a sinusoidally varying wave to change its phase with respect to a fixed reference by 2π The phase velocity v_p is equal to the product of frequency f and wavelength λ that is $v_p = \lambda f$

The magnitude of phase velocity is determined by the intrinsic properties of the medium in which the wave is propagated and by the actual mode of propagation For small amplitude acoustical waves in a quiescent unbounded gaseous medium the phase velocity is essentially independent of frequency and equal to the speed of sound c in the medium This speed is given by the equation $c = \sqrt{\gamma P_0/\rho_0}$ where γ is the ratio of specific heat at constant pressure to specific heat at constant volume P_0 is the ambient pressure in the medium and ρ_0 is the ambient density of the medium In a perfect gas the speed of sound becomes a function only of the absolute temperature of the medium In air this quantity is approximately $c = 49.03\sqrt{R}$ ft/sec, where R is in degrees Rankine or $c = 20.05\sqrt{T}$ m/sec where T is in degrees Kelvin The phase velocity of electromagnetic waves also depends on the medium but in a vacuum the velocity c is a universal constant approximately equal to 3×10^8 m/sec

Waves in a medium which require higher than second order equations for their description such as lateral vibrations of a bar generally have phase velocities which are dependent upon frequency Thus waves of different frequencies travel with different velocities resulting in dispersion *See* GROUP VELOCITY WAVE MOTION [W J G]

Phase angle measurement

The determination of the relative times at which alternating currents and voltages in a circuit take on zero values If two voltages v_1 and v_2 are zero at the same instant they are in phase with zero phase difference (or out of phase with 180° difference) If one voltage v_1 passes through zero ⅛ cycle before a second voltage v_2 it leads by 360°/8 or 45° (see Fig 1) The common phase meter a commercial device for determining the angle between current and voltage can be used when its presence will not disturb the circuits under measurement (see PHASE METER) When the phase angles to be measured are in high impedance or low power circuits this instrument is unsatisfactory and other measurement methods must be employed

Three voltmeter method This method can be used when the voltages involve a common point Figure 2*a* shows three terminals *a* *b* and *c* If the voltages v_{ab} v_{bc} and v_{ac} are measured by a high impedance voltmeter (one voltmeter is sufficient) the magnitudes can be plotted to give a triangle Fig 2*b* The angle θ between v_{ab} and v_{bc} can be determined from the law of cosines in trigonometry

$$v_{ac}^2 = v_{ab}^2 + v_{bc}^2 + 2v_{ab}v_{bc}\cos\theta$$

Electronic phase angle meter This instrument gives the angle $(\pi - \theta)$ of Fig 2 directly One

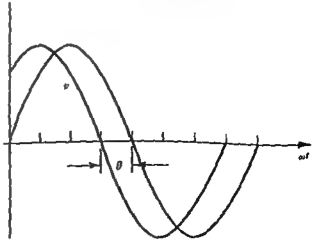
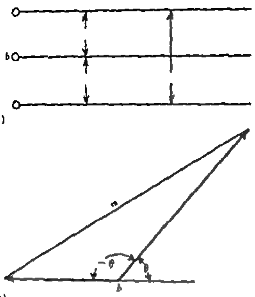


Fig 1 Phase angle between two voltages



Fg 2 Volt g mpl y d n th ltmet m th d ( ) C t d g m (b) V t d g m

u h i tr ment n erts th two lt ge wa e t q are wa e by r p ted ampl f at and limit g Th e c ng f the qu e wa e a e dent al t th z e s i g of th g n l lt ag w The tw q re wa re appl ed t th np t of rc it that w ll p ur e t ly wh both q a wa are po t s In th e the g at r th l g of oltag the malle th e l p f th p ti p t n d the lowe the rr t The u re t i th e s pr p t nal t θ f Fig 2

This r u t has th theo tic l limit t n that ch put lt ge mu t be gr ate th t l m mum al l p a t ce th c at l alue s de t m ed by th i e th mpl fi i put If the lt g t l w th r e u e r d m zer e g h ft d the ult w ld l s bje t t th rt nty

A p i n ph gle m te f r h gh f equ n y lt ges abl d l y l and ts pe a t o h d o the f t that the d ffe e f two oltag f n ta t mpl tude a mi m m when th t e ph O f the t lt g s t h omp red s t d t both p t f a a bl d l y l wh ch th n adj t d t e m m m utp t Th tw lt g s to b e mp ed a th o n ted t th tw te mi l a d th d l l i dju ted to g m m tpit Th h g th del y h ett g g th t m d l y f ltage elat t th th Wh th (I y k w th t m d lay a b m put 3 a gl f lag If Δt i the h ng th del v l tt g nd the f q) f y l p r d tt ph e angl g e by 2 $f \Delta t$ adi 360$f \Delta t$ deg e

Oscilloscope methods Pl ngle me e m nt by sc ll p s p p l th labo tory whe q k pp m t lt q ed ll one ltage i c n ted t the vertical a) lifi r and tl tl er t the h riz ntal ampl f r a l i a j u f gure i cl ta e l

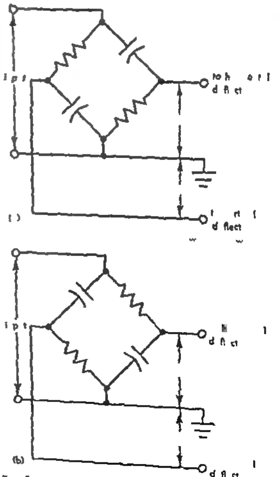
If th tw ltage are f tl e ame fre j ency i the ca e wh n j l a ngles are m a ured tl e ba ic f gure s an llip e A traight line with a po itive l pe impli tl at th tw w are in j ha If on lead tl tl er tl e cath de ray l am t rt la k m ne d recti n l ef e it r a le a ma imum n the othe and tl e ray tra e an ll j

If tl e ampl fer a e adju ted s that the l riz n tal amplitud i q ial t tl erti al amplitud the lope f the st a ght line f r in pl a e sign l i 45 Tl e ellipse wid n to a cir l wl en tl e pl a ngle is 90 Intermedi te alues a e ind cat l l y the f rm la

$$\tan \frac{\phi}{2} = \frac{b}{a}$$

wh e ϕ i the pl a e angl ught b i tl w lth f the ell p e a d a i its lengtl *See* LI AJ C L S FIGURES O CILLO COPE CATHODE RAY

A the meth d f ut liz ng n scill c p de el ped l y th utl may l ill tr ted l y the f l low n id ratio s If a signal i applied acr s



Fg 3 B ut fo m u l g ph gl w th ll p f ( ) Cl kw w p g t d (b) C t l kw c l w p g t d

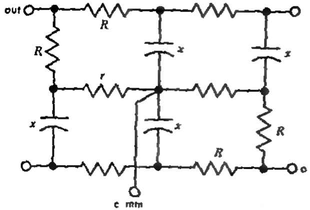


Fig 4 Actual circuit for measuring phase angle with an oscilloscope

the input of the bridge circuit shown in Fig 3a the output voltages e_1 and e_2 will be 90 apart and if r equals x (equals $1/2\pi fC$) they will be equal in amplitude Now if e_1 and e_2 are applied to the vertical and horizontal amplifiers of an oscilloscope the resulting trace will be a circle If r and x are interchanged as in Fig 3b the trace will again be a circle but the spot will trace the circle in the opposite direction

If these two circuits are combined so that the sums of the outputs are applied the spot cannot go around the circles in opposite directions at the same time and it will trace a straight line instead As the phase of one voltage is advanced say by the angle $\Delta\theta$ the straight line will rotate on the screen through the angle $2\Delta\theta$ A scale can be marked on the screen and either end of the straight line used for reference The presence of harmonic and slight errors in the $r = x$ relationship or in the equality of the input voltages will cause the line to open into a narrow ellipse The slope of the major axis of the ellipse in this case is used for the slope of the straight line Figure 4 shows a working circuit It is built so that $r = x$ at the operating frequency and R is several times x so that the voltages are added without appreciable loading of the bridge circuits

Electronic switch An electronic switch can be used with an oscilloscope as a phase angle meter The switch permits the oscilloscope to display first one wave and then the other If the linear sweep is at the same frequency as the waves being compared the two waves will be superimposed on the screen The phase difference and the period can be measured on the screen in inches the ratio giving the phase angle as a fraction of 360

Phase order indicators These devices are used to indicate which phase voltage of a polyphase circuit leads or lags another If the voltage vectors of a three phase generator are as indicated in Fig 5a the voltage from neutral to line 2 reaches a maximum ⅓ cycle (or period) after the voltage from line 1 and ⅓ cycle before the voltage from line 3 The voltage of phase 2 lags that of phase 1 and leads that of phase 3 The phase order or phase sequence is then said to be 1–2–3

Relative motion between the armature conductors and the magnetic field induce the voltage in an alternator Therefore if the alternator were rotated in the opposite direction the order in which the phase voltages reached maximum would be reversed The phase sequence would be 1 3-2 as shown in Fig 5b

A miniature three phase motor designed to rotate clockwise when connected to a three phase system possessing a phase sequence 1–2–3 is used as a phase-sequence indicator Counterclockwise rotation would indicate a 1–3–2 phase sequence

A common type of phase order indicator consists of an inductance and two lamps connected in Y to the three phase line as in Fig 6a If we assume that the inductive reactance is very high the common connection on the Y is at a voltage nearly equal to the midpoint of line 2–3 in Fig 6b and c The voltage across the reactor is E_{n1} and the current lags by 90 and lies on $n2$ in Fig 6b and on $n3$ in Fig 6c This current divides part going through each lamp The result is to increase the current in lamp 2 when the phase sequence is 1–2–3 and to increase the current in lamp 3 when the phase sequence is 1–3–2

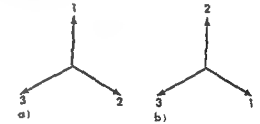


Fig 5 Phase sequence (a) Sequence 1–2–3 (b) Sequence 1–3–2

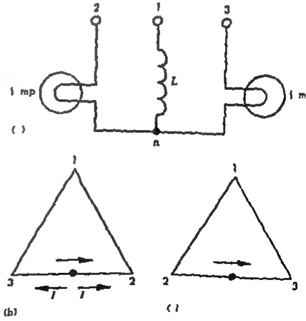
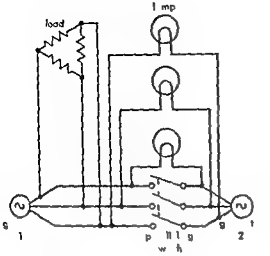


Fig 6 Phase sequence indicator (a) Circuit diagram (b) Vector diagram for sequence 1–2–3 (c) Vector diagram for sequence 1–3–2



Fg 7 P ll 1 g d g t with f t l dy u d l d

Phase relation indicators Th e d ces a e f t d at tl m t nt h n t g e at f alt ting lta e a e gl w tf n the lf tw lt ges ea h ma m m at the m t m th n ph e Wh n tw a t b n t d p llel th y h ld h e the m lt f eq n nd ph A ltm te d t h m t a he d t ndi ate wh n the lt g nd f eq a n a l q ral The pha l t n b tw the two u e s h wn by m f pha g l mp by m f synchro- p h

Fh l mp pl d a th p w t l u d t pa all l t g e t ll fte ffc to d t n pha e c nd t t F 7) De p d p n the l tt e ph f th t o ma l th l mp lt a f m th m t the d ff n f the m h ltag A th tw f e q n pp h n th th l mp flcke h t f m f ll b ght t d m t a d c g at If th t f q a e q l th lamp w ll m t n a f d b ll a ll ll tl m g m h t th a l ght l ghe f q y o th t it ll t k p m l d the th b n dd t n l l d tl tem A th l mp l wly g th h th d m ph th wit h l d t g tl m h t th tem

Synchronizer or synchroscope Th t a a a t f th T m ph m t Th nt th fix d l ppl cd b ma l n th t n th m bl d l t appl ed by th th m h If th tw m h t hro- m th t f q a q l a d the c d l ll t k p t d p nd p th l t ph a gle If th f q y f e m h b htl h he th ph w ll nt t d th d l ll t t a d t de l t f C ll th m h g l ghtly h gh p ed d t d t th l h tl h p p nt d ft p t th

ma k See ELECTRICAL MEASUREMENTS POWER FACTOR METER WATTMETER [H O]

Bibliography C R Partridge *Principles of Electrical Instruments* 19 8 M B St ut *Basic Electrical Measurements* 19 (

Phase modulation detector

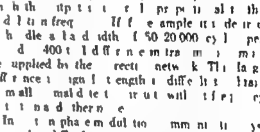
A d c f r the det cti n f pl a e m d lated ad g al Pha e-m d l ted ignal l e d t cted n a man er id nt c l t that d with fre quency m d ilated g al leca tl e e n ti l d ff rence l etween tl ese f rm f m f l ti H w er l ca e the m l lat n ind x ri d ff rently w tl m l l t fr q n y freq ne m d lat n detect r ed t f m f f f l y tle ad l t n f l w p nt tk t wl l l the m l t de t made t ary in er ly w ill tl m l l t n freq en y W th tl dditi n any f eq ncy m d l t d tect an l e m d t perat att f t ly f r tl e d mod lat f pha e m l lated wa S e FREQUENCY MODULATION DETECTOR

T demod l te pha mod lated way will t ampl tu d d t rt th ignal d ri l fr m a fr que cy m d l ti n d te t r m t l e r ected l ng tl e tput th gh a l w p filter in h h th tp t t t r l pr p ti al t th m d l ti n freq If f e ample it t de ir d t h dle a l a d idth f 50 20 000 cy l per d 400 t l d ff r n e m tra m mi t le applied by the recti netw k Tl i la g d ff r nce t ign l t ength t diffe lt t l tai f m all mal d te t it u t will t f r q cy d t t n a d thern e

In t n pha e m dul tio mm nt li y- t m the diff ulty ju t m nti ned parti lly l m n t d l y mpl ying t an mitter p e mphas that de a g th degree of mod ilat the l gh r m dulat n freq t n te If d tl er f the p mph etw k m t l e mpl ed at the det t dd ti n t tle r ct e n tw k m t n d S DETECTOR [F L C]

Pheasant

A y f ma y f wl l ke l ds of th family Pha n d prim rily c r ing in s utle t rn l ia with a m m b utiful pecc ati t th a t Ch n T b t B ma and tl M lay Pe ula Ph nt are h racte d l t kt g pl mag l g t l pu d leg nd the l ne

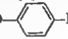
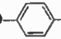
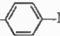


Th 9 k d ph t Ph f h le gth t 3 ft (F m E L P lm F ldb k f N t l H t ry M G w H ll 1949)

of feathers on the sides of the head They eat grain weed seeds berries insects and snails Pheasants have been raised by man for many centuries first reaching western Europe through introduction by the Romans

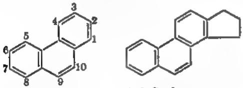
The ring necked pheasant *Phasianus colchicus* has been repeatedly introduced into the United States and has become well established over a wide area of the northern United States and southern Canada where it ranks as a major game bird *See* GALLIFORMES [J D B]

Phenacetin

One of a general class of medicinals known variously as analgesics antifebrins or antipyretics of which acetanilide is the best known Phenacetin is an acetyl derivative of *p* phenetidine It is made by the reaction of NaO—  —NO_2 with C H_5Cl to form C H_5O—  —NO which is reduced to the corresponding amine and acetylated to form phenacetin C H_5O—  —$NHCOCH_3$ The reaction is continued as a cyclic process in which phenol acetic acid and ethyl chloride are continuously upplied Phenacetin is less toxic than acetanilide but it lowers the ability of blood to combine with oxygen *See* ASPIRIN HYPOTHERMIA [A L H]

Phenanthrene

A colorless cry talline hydrocarbon (C $_4H_{10}$) which melts at about 100 C and boils at 332 C Phenanthrene is usually obtained from coal tar



Phenanthrene 1 2 Cyclopenteno phenanthrene

but it may also be produced by the hydrogenation of coal Since carbazole and anthracene (usually pre ent in crude phenanthrene) form mixed crys tals with it commercial grades of phenanthrene usually melt at higher temperatures than the pure compound

Phenanthrene may be hydrogenated in the pre ence of coppe chromite to yield 9 10 dihydrophenanthrene or it may be oxid ed to yield 9 10-phenanthrenequ none In general substitution re actions yield a m xture of products which are difficult to epa ate

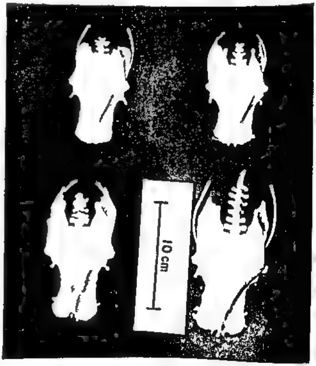
Phenanthrene has little commercial importance It i of intere t becau e the nucleu is f und in ome ie in acids and is produced by the degradation of certain alkaloid Reduction products of 1 2 cyclopentenophenanthrene may be regarded as f rming the keleton of the ster ids *See* AROMATIC HYDROCARBON POLYNUCLEAR HYDROCARBON STEROL [C K B]

Phenocopies

Nonhereditary variations of form or function resembling mutant trait but cau ed by external con ditions during development They occur pre um ably in all types of organi m spontaneou ly or after experimental intervention Pre ent knowl edge of phenocopies is derived chiefly from work on *Drosophila melanogaster* and chicken embryo

In hereditary (dominant or reces ive) rumple ness in the chicken a well as in the in ulin produced phenocopies the abnormalities vary from complete absence of all tail vertebrae to conditions deviating only slightly from the normal one The specimens shown in the figure are of different a e and sizes but illustrate an intermediate condition with abnormal and fused tail vertebrae The e in termediate conditions are cau ed by the pre ence of modifying gene which prevent the mutant genes or the phenocopy inducing agent from exertin their full force De elopmental tudie have hown that the insulin induced phenocopy is more clo ely akin to recessive than to dominant rumple ne s.

The phenocopy producing agents may be phy i cal for example heat shocks x ray or chemical agents The principal respon e determinin factors are the developmental tage at exposure the force of external agent and the genetic con titution of responding organism Unrelated phenocopies may be produced in different tages by the ame agent and by different agents in the ame stage The force or dosage of the external agent is chiefly a ource



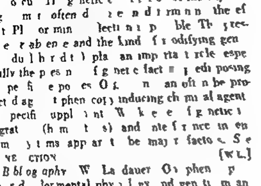
P l c bo a d t l rt b a of a m l h cke (pp r l ft) o w th dom a t mpl (pp ght) o w th rec s mpl (l we l ft) a d o e p od c d by i ct g l to th d l p g egg ft 4 d y of bat (l w ght)

f quant tat e va ti n n tl i den e and t pe f re p n e but q al tat e e pon e d ffere e m o cu Tl g netic t t t o of the expo ed rg m r often d e e n d r mn n the ef fe t Pl or min lecti n t p ble Th y ree n e r ab en e and the kind f r odifying gen (r du l h r d t) pla an imp rta t rcle espe ally the p es n f g net e fact n p edi posing t pe fi e po es O g n an oft n be pro tect d ag t phen co) inducing ch mi al agent b pecifi uppl nt W k e e f g netic tegrat (h m t s) and nte f r nce in en zym y t ms app ar t be maj r facto s. S e G NE CTION [W L]

B bl og aphy W La dauer On phen p th r d lopmental phy i l gy nd gen ti m an n *Am N t al* 92(865) 201 213 1958

Phenocryst

A el ti ly l rg ry tal mbedd d i a finer gra ed gl y on u rock The p n e f ph no r sts g e the rock a p rphyrit c t t r Phen y t re pre e ted mo t comm nly by f ld p qu rtz, bi t te h rnbl d p ox n a d ol ve Strictly p king phe ocry ts c y tall ze f m m lte ock m te al (la magma) They



G t (q rt m o t) f m th S N d f C lf how ng m ph ry t f m l f ld p n ll l t no w th b d d t ct f th k Th ph o ry t pp t h pl d th d ll d p phy bl t H mme i 10 i g (USGS ph t g ph by W B H m lt)

mmonly ep e t an tl a d lower t g f *ry tall zation* th n lo s th m t x n wh h th y mb dded Phe o t r t be di t gu h d f om ert zel t ely l g ry t ls (p rphy o bla t) wh h d l p l t l d k s the e lt f m t ph m r m t m t m If th) f a larg c y tal s t q e t th n g t t m m gs ry t ho ld b used S A RE OLE CO T CT IC OC ROCKS PORPHYROBLAST P R HYRY R ANI I GR NITES [C A C A]

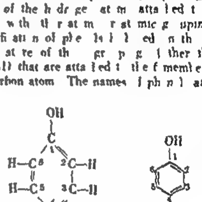
Phenol

O l la *of c d* gan mp nd who t mm t t ral f atu hyd yl g p t t h d d tly t an m t g y t m

Ilen l (Iydr xylenz ne) i t xi t all types f living cell In c ncentrated f rm it pr d i es er kin l rn Phen l i g neral a e t xi to mi r rgan m Ph nol it elf n dilite luti n wa the fir t delil rat ly i ed anti ptic an l m ny ph n l are n w u ed f r tl p rpo e Pi ric acid is u ed to treat l urn

Uses The cl ief e f r pl en l i in tl e ma ufa ture of phenol f rmald hyd re ns and pla ti f t t i al o a raw m t rial required f r tl prep aration of re complex phen l *wl ich are u ed* a drig d i fectant nt i ti fung cide in ecti ide wood pre erv ti es *a t lant pre r ati es f r g* sol n il r ller lat an l f od tuff *a d in tl e man ila tu e l dye plas* t z r weed k llers, d t rgent an l poxy res n *The annu l producti n of phen l in the United* Stat n w eed 500 000 000 ll

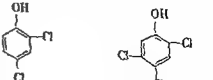
Structure and nomenclature Tl mpl est mem b r of th l i phen l al known a carl l c d St i ture l th r *meml r* l the cla n e d r ed fr m th t f phen l l y repl ci g n or m r of the h dr ge at m atta l ed t ca l n t m w th tl r at m r at mic g uping The cla fi ati n of pl e l l l ed n th n mber a d at re of th gr p g l ther tl n l y d xyl) that are atta l ed t tl e f meml e ed r ng of arbon atom The names f ph n l are l i ed



G aph formul *Simpl f l f rmula*

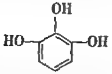
Ph nol (arbol c a i l)

th gnm t f uml r t the carb at m *f th aromatic* ng The arb n at m atta h d t th hydr xyl gr up i a ig ed the n ml r l and the fi e ems g E n at m are th n numbered c t ly If b t ne at m r gro ip located n the ar m tic r ng at po tion ll thi gro p s a d t be rth ( ) to tl e h d xyl gr up f it e o d g p loc ted at po i n 3 it is m t (m) t p tion 4 t i p a (p) If tw m t m r g p in add t n t th l yd o yl p ct th po t o a d gnated by the app p t umb rs.



4 D bl roph l

Phenols whose structures contain more than one hydroxyl group bound to an aromatic ring system are called polyhydric phenols Examples are catechol resorcinol and hydroquinone all dihydric phenols Pyrogallol a trihydric phenol is a photographic developer Phenols in which one or more



Pyrogallol

hydroxyl groups are joined directly to an aromatic system comprising two rings of carbon atoms are represented by the naphthols *See* NAPHTHOL

Production Phenol is produced by four competing processes (1) The benzenesulfonate process involves the sulfonation of benzene by concentrated sulfuric acid and then fusion of the sodium benzenesulfonate with caustic soda

$$C_6H_5SO_3Na + NaOH \rightarrow Na_2SO_3 + C_6H_5ONa \xrightarrow{\text{Acid}} C_6H_5OH$$

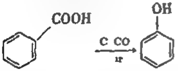
(2) In the chlorobenzene (Dow) process chlorobenzene is treated with caustic soda in the presence of copper at elevated temperatures and pressures

$$C_6H_5Cl + NaOH \rightarrow NaCl + C_6H_5ONa \xrightarrow{\text{Acid}} C_6H_5OH$$

(3) In the Raschig process benzene is first converted to chlorobenzene by hydrochloric acid and air in the presence of a catalyst and then the phenol is formed from chlorobenzene and water in the presence of another catalyst (4) In the cumene peroxidation process cumene hydroperoxide formed by the action of air on cumene is converted by sulfuric acid into phenol and acetone

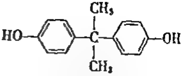
$$C_6H_5CH(CH_3)_2 + \text{air} \rightarrow C_6H_5C(CH_3)_2OOH \rightarrow C_6H_5OH + (CH_3)_2CO$$

A more recent process consists of heating benzoic acid in air in the presence of copper carbonate

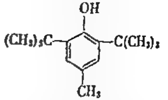


Less than 5% of the phenol now manufactured in this country is obtained directly from coal tar More complex phenols are prepared from phenol itself or by the adaptation of one of the methods used to prepare phenol to appropriately constituted aromatic compounds

Complex phenols Bisphenol A is made from phenol and acetone and is an intermediate in the preparation of epoxy resins 2 6 Di *tert* butyl 4-methylphenol is made from p cresol and isobutylene and is used to protect gasoline oils rubber and foods from deterioration caused by atmospheric oxygen Pentachlorophenol is used to protect wood against attack by fungi and termites Its sodium salt is used to treat industrial water to pre-

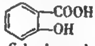


Bisphenol A

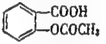


2 6 Di *tert* butyl-4 methylphenol

vent the growth of slime and algae Salicylic acid is an intermediate from which aspirin and other analgesic drugs are made 2 4 Dichlorophenol and

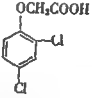


Salicylic acid

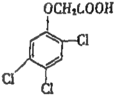


Aspirin

2 4 5 trichlorophenol are intermediates in the manufacture of the weed killers 2 4-dichlorophenoxyacetic acid (2 4-D) and 2 4 5 trichlorophenoxyacetic acid (2 4 5 T) which are usually used as their salts or esters

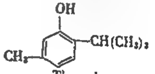


2 4 D

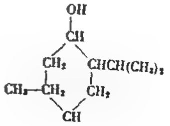


2 4 5 T

Some phenols occur in natural products For example thymol from thyme oil is used in dilute solution as an antiseptic and as an intermediate from which menthol is prepared The toxic agent

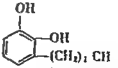


Thymol



Menthol

in poison ivy are related to catechol one of them



3 (*n* Pentadecyl)catechol
(from poison ivy)

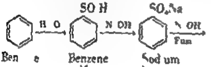
1,3-(...)catechol. *See* PARA-AMINOPHENOL; CATECHOL; CRESOL; HYDROQUINONE; PICRIC ACID; RESORCINOL.

[R.B.C.]

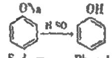
Phenol formaldehyde resin

One of the condensation products of phenol or phenol derivatives with aldehydes such as formaldehyde and furfural. The term phenoplast is sometimes used to refer to the whole group of products. The phenol formaldehyde resins developed commercially between 1900 and 1910 were the first truly synthetic polymers and have found wide usage for electrical insulation, molded objects, shell molds for metal, laminates, adhesives and many other applications. They are characterized by low cost, high strength and resistance to aging.

Phenol is prepared by the direct oxidation of benzene, by the hydrolysis of chlorobenzene or by the alkali fusion of sodium benzene sulfonate.



Benzene — Benzene sulfonic acid — Sodium benzene sulfonate



Sodium phenolate — Phenol

Resins may be obtained by the alkaline fusion of *m*-benzene disulfonic acid and *m*-cresol from coal tar also used.

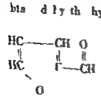
m-Dihydroxybenzene (resorcinol) — *m*-Cresol

Formaldehyde is produced by the oxidation of methanol or methylal alcohol.

$$CH_3OH + O_2 \xrightarrow[50\text{-}600°C]{\text{C catalyst}} HCHO + H_2O$$

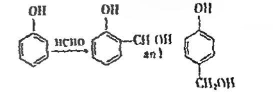
Methyl alcohol — Formaldehyde

and furfural is obtained by the hydrolysis of oat hulls.



Furfural

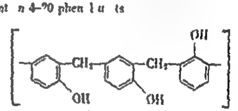
Polymerization. In the presence of alkali, phenol and aqueous formaldehyde react to form a mixture of phenol alcohols or methylolated derivatives with the methylol group in the ortho and para positions.



A-stage resin: methylol phenol

The methylol phenols are soluble, fusible materials which are generally called the A-stage resin.

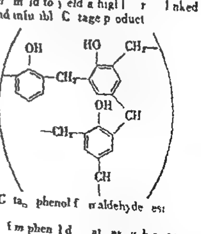
In the presence of acid and less than 0.86 moles of formaldehyde per mole of phenol, the primary alcohol reacts to yield diphenylmethane polymers called novolacs which are soluble and fusible and contain 4–20 phenol units.



Novolac resin

By further heating of the A-stage resin or by the addition of more formaldehyde to the novolac, further condensation takes place with the formation of the B-stage product, a brittle resin that is partially soluble and fusible.

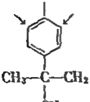
In the production of phenolic resin molding compositions it is common practice to neutralize the resin, heat and dry the B-stage resin, to mix it with fillers and curing agents, and then to compact it into the form of pellets or briquettes. The curing agent is hexamethylenetetramine, which at the temperature of molding reacts with water to form formaldehyde and ammonia. In the presence of ammonia and the additional formaldehyde, the B-stage resin cures in the mold to yield a highly cross-linked insoluble and infusible C-stage product.



C-stage phenol formaldehyde resin

By use of *m*-phenol derivatives such as resorcinol and *m*-cresol, resins are obtained which cure rapidly at low temperature because the meta substituents activate the ortho and para positions. By use of ortho or para alkyl phenols such as *p*-*t*-butylphenol, which have only two active sites available

able for reaction (difunctional)



oil soluble thermopla tic re ins are formed instead of the cross-linked materials obtained from the tri functional phenols just discus ed The e products being som what more expensive than the ordinary phenolic resin are used in special paint varnish and adhesive formulations

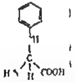
With the use of furfural instead of formaldehyde the B tage re in has the unique property of re maining thermoplastic for a relatively long time The phenol furfural compo itions are useful for molding large complex forms in which extra time is needed for the re in to fill the mold completely

Fabrication and use Phenolic resins can be cast from yrupy intermediates that are cured by heat ing Laminated products can be produced by im pregnating fiber cloth wood and other materials with the resin After heating laminated sheets can be pre ed into any shap s de ired Most of the phe nolic pla tics can be machined if necessary

Cured phenolic plastics are rigid hard and re i tant to chemicals (except strong alkali) and to heat

Some of the uses for phenolic resins are for mak ing preci ely molded articles uch as telephone parts trong and durable laminated boards or for impregnating fabrics wood or paper Phenolic res ins are also widely u ed as adhesive as the binder for grinding wheels as ion exchange resin and in paints and varni hes S e ADHESIVE PHENOL PLASTICS FABRICATION POLYMERIZATION TEXTILE CHEMISTRY [J A M L M H]

Phenylalanine



Phen lal ne

Ph y l stant f h 2
pK (COOH) 1 83 pK (H) 9 13
I oelec pH 5 48
[ ] (H O) −35 [ ] (HCl) −4 5
( ) (g 100 ml H O) 9
Absorpt pe rum pe k 60 ( ) let)

An amino acid considered es ential for normal growth of animals The amino acids are charac terized physically by the following (1) the pK or the diss ciation con tant of the various titrata ble groups (2) the i oele tric point or pH at which a dipolar ion does not migrate in an electr c field (3) the optical rotation or the rotation im parted to a beam of plane-polarized light (fre quently the D line of the odium spectrum) pass ing through 1 decimeter of a solution of 100 grams in 100 ml (4) olubility (5) absorption spec trum or the wa elength at which maximum absorp tion occurs See EQUILIBRIUM IONIC ISOELECTRIC POINT OPTICAL ACTIVITY SPECTROPHOTOMETRIC ANALYSIS

Dietary phenylalanine is the source of tyro ine in animal tissues Phenylalanine originates bio synthetically from phosphoenolpyruvic acid and D erythrose 4 phosphate by way of shikimic acid and prephenic acid (*see* AMINO ACIDS)

During metabolic degradation the major path way in mammals is by oxidation to tyro ine which is then degraded to fumarate and acetoacetate (*see* TYROSINE) Phenylalanine also can be deaminated to phenylpyruvic acid of which three metabolic products are known benzoic acid phenylacetic acid and phenyllactic acid [E A AD]

Phenylpyruvic oligophrenia

A type of mental deficiency caused by an inherited defect in protein metabolism specifically the me tabolism of phenylalanine (*see* PROTEIN) It is also known as phenylketonuria The condition i rare with an incidence of 1 in 25 000 in the gen eral population and 3 in 2300 mental deficients However re earch has created the po sibility of preventing ome types of mental deficiency cau ed by mutant genes through medical identification of genetic factor in the parents (*see* HUMAN GENET ICS)

Phenylpyruvic mental deficiency is identified by the presence of phenylpyruvic acid in the urine The addition of a 5% solution of ferric chloride to the urine causes the formation of a characteri tic deep green color in the presence of the acid Po t mortem examination of affected case di clo e ab sence of the liver enzyme respon ible for the me tabolism of phenylalanine in normal per ons (*see* ENZYME) The concentration of unmetabolized phenylalanine is as ociated with diminution of ac ti ity in the hi her mental center and in perma nent ntellectual retardati n

It is po sible to alter the amount of the excre tion of such al normal m tabolites by alteri g the amount of phenylalanine in the diet Phenyla lanine free d et have b n de eloped and their efficacy i under study There are ome indication that if diet c ntr l can be appl ed in early infancy damage to the ner u v tem can be halted and a more normal m tu ati n ant ipated

The mental defecti e of this type i u ually blond with blue eye fair kin ign of eczema and a typical musty od f the urin Frequent bizarre beha ior rea t n in l li g withdrawal fright reaction negati m a d p t ir ng are common in me ca e Th a e ge erally h w e ere mental retar lat n alth h ca si nally they may l e cla ifi d a m l rate They rarely benefit from spe ial edu at n in tl e p il li chool or from re ident l fa ilit

From the po nt of iew of g n ti th n litt n i d e t a single mutant gene an l f ll w a typi cal rece i e pattern f inheritan e It tim ted that the gene exi ts a a rece in l 173 in tl e general p pulati n The par nt ar app r ntly normal heter zygote with n o e t f al dence f the di ea e while tl ppe ar

h m zygote w th bv u m nt l deficie y d the m ked s gn of an al n rmal ub t nce in th u ne Rece t tude of tl hete zyg us pa nt ha d m n t ated abno m l phenylal n ne toler anc curs Th all ws the p b l ty f pre d ct g the ex t nc f the re e g ne a d the p ob ble c ur ce f a h m zyg te ff pr ng S h a techn q mav p de a o cret ba f r med cal d which w ll p ot t uch pot nt al pa ent f m r pr du i g and th s reduce the in denc f the d e i the ge l p pulat n *S* MENTAL DEFICIE CY [M C K]

Phlebitis

An i fl mm t n of the wall f a u ually as s ted w th a l t formati n o th mbu i th l \ th mbo s of tw mai types phl b th mb s w tho t infl mmat n and throm b phl b ti wh re infl mm ti n i l d The cau es e not c mpl tely unde stood ne rthe l i d i g fa t r n lude blood sta i as n p l n d b d e t t n de tr t on ard ac f fur bes ty va i o t es d i f t ns f a l al r y t m n t r A a th ombus formed n m tte what the gu e port n may b eak ff t b m mb l Th mbol may lodge i the l g with ata t ph r lts

I me a f mat f tl omb pr d ce a i flammat v e t on f the adja e t l all If l ry fl late l l t n es t bl h d a ly t may l es the o g t n and ll d i age f bl od f m th ff t d re In th b e of n u d i g i s effect m y n e n l d n d r n te d rn le er a d g g ne *S* CIR L TION EMBOLI S CAN G ENE P I EEP THROMBOSIS

O e lly phl b ti m y de el p w tho t a p ed g th mb a whe t u fe t on p d d r t nfl mm t n f chl b t ften d t ll alt s b th blood l all a d the l i n l f mity o de t t n f th s l e mm l a d the e turn t p e ip t t n f et in tl e fo m ti n of r e n th e t bl h g e us es le of ta tl mb a d fl mm tion Fld ly i d du l e e p i lly pt bl to phl b t b s f th f q n i f p u l mp i d i l t

M lk f i tl f v t f r L th pl l t nd lymph el flamm t o e ated with me r ne [E C S T]

Phlebotomus fever

A m ld e t borne u d e o e rr ng m m l M d t r ea e t d Ru Cl d Indi fi l kn w a dfly feve Tl l i ? m d et A t g n l t h p r t th a tf p d b e i l a i l d m n t i d

Aft n l f n nf t d f m l *Phl b t mu* p p t tl pat i d lp l d h m l i i v i n se p i t ffn s All tt t ec Cl l d g o m y b onfirmed f t l d blood

In endem c ar a immuni ing infecti s are ac qui ed l y m t children Outl reak occa i nall mi taken for malaria oc ur wl en u ceptil l adult i h as military troop enter an endemic ar a Pre ention i b e ntr l f th v ct r *S e* ANIMAL VIRUS [J L M]

Bibl og phy T M Riv rs and F l H r fall Jr (ed) *I i al and Rickettsi l Inf ctions of Man* 3d ed 1959

Phloem

The ch ef food conduct ng ti ue in va lar plant It c nduct ng ell are known as ie e ele ments b t phloem may al o include companion cells parenchyma cell fi er sclereid ray and erta n other cells Phl em is pat ally a c ated w th xylem and the tw t gether f rm the a cular i tem M h less is kn wn f phl em than f xy l m pa tl l ecau of it les er direct ec nomic importan e and partly be au th ie e elements funct on f r a h rt tim (c mm nly one sea n) and then underg ma ked truct ral a d f ncti n l changes in l ding r h ng and in woody plant sl ugl ng off a result of periderm f rm t n (*see* PERIDER I) Furth the devel pm nt of phl m mo c mple than that f tl e xylem and r l abl inf rmat n in thi rega d is ants

Sieve elements S eve elem nt d ffer fr m p re chyma cell n the structu e f th r wall and in the un qu h ra ter of the r p ot pl t (*see* CELL PROTOPLAST l ARE CHYMA) S e area di tin ti e st uctures in ie e element w ll are sp ial iz d p imary pit field in whi l the pla m d mata (fi e tr ds f c topla m) bec me larged a c nnecting t nds d nc d in el ngate callo c ll r (F g 1) Tl e w ll of e lem t ften e e in th kne by the depo it n f the so called na eou th cke ing The prot pl t of a i u g immat e si e el me t not be d tin gui hed f m that f a typical p chyma cell f tl same age In th c e f development into a fun ti ing e lement h were sev r l d s ti t cl a g s Sl me fi ies f equently ap pe r and l t fu e t amo ph us mas of slim th nucl s di i i g t (lth ugh the nu cl l s may c p and etain its d nt ty) the bound ry b tw en th pr topla m and th ac i le b m t d t n t nd tl e protopl m event ally be m v t ally n ta nable by rd na y l to log al dye Pl t d ir ducing a b hydrate of p ula h ra te may be pre ent O or mor of these f ture m y l e bse t fr m tl e ie e ele m nt th l f u l n i th mo t c mm n fea t

A a e e leme t b om nonf nct ng t ont nts di integrate Th c ll fir t in rea s in m unt nd then di ppea s al ng with the con ti g t and lea i g empty p n th wall Th el m nt be mes filled with i d may be c ush d late by l rg m nt of rr un li g pa l yma ell

Sieve cells and sieve tube members Typ cal ev ll l g l ments a whi h all th eve r a e f qual speciali t on th gh s e

areas may be more numerous in some walls than in others In contrast a sieve tube member has ome sieve areas more specialized than others that is the pore connecting strand and callo e cylinders are larger in some ieve area Parts of the wall containing uch sieve areas are called ieve plates Simple sieve plates have one specialized ieve area that generally occurs on a tran ver e end wall compound have two or more on an oblique end wall Sieve tubes are composed of an indeterminate number of sieve tube member arranged end to end Thus ieve tubes are to the phloem what ve els are to the xylem Sieve tube members are horter than sieve cells and become progre i ely more o with evolutionary change *See* XYLEM

Companion cells Companion cell are pecial ized parenchyma cells that occur in close ontogenetic and physiologic a sociation with ieve tube members They arise from the same meri tematic cell that produces the sie e-tube member and vary in size position and number but always retain their nucleus Some sieve tube members lack companion cells The precise functional relation ship between the e two kinds of cells i unknown, but they become nonfunctioning simultaneously

Parenchyma cells Parenchyma cells in the phloem are thin or somewhat thick walled and oc cur singly or in strands of two or m re cell They store tarch frequently contain tannins or cry tal commonly enlarge as the sieve elements become obliterated or may be transformed into clereid or cork cambium cell . Parenchyma cells in ec ondary phloem may ari e from a meri tematic cell (phloem initial) producing only such cells or from one that also eventually produces one or more sieve tube members and companion cell Paren chyma cells seem to intergrade with companion cells in the angio perms

Fibers Phloem fibers ary greatly in length (from a fraction of a millimeter in ome plants to ½ meter in the ramie plant) The secondary wall are commonly thi k and typi ally have imple pit

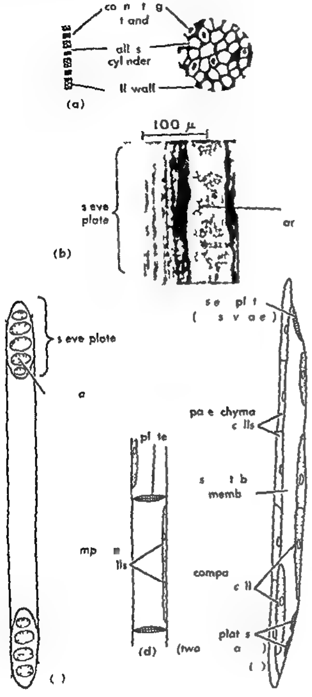


Fig 1 (a) Part of e pl te u face v ew on nect ng t and a d wall (black) callose cyl de (cl ar) (b) Phot m crog aph of rad al sect on of pa t of the se ondary phloem of Ame ca sy amo e (Plat a occ d ntal s) show ng the e e a e s on th compou d s e e plat of s e tub s (Fo st Pr d ct Labo at y USDA) ( ) Obl q e plates w th e al e a a r e d w ll of s e e tube membe (d) Lo g t d nal s ct of a s gle s t be m mber a d parts of two othe s s mple eve pl tes on t s ve e e d wall a d two compan o cell ( ) As mblag of ell d r ed f m o phloem n tial s e tub m mbe w th s e plat s (h t hed) on e d wall st nd of pa enchyma cell w th n cle a d compan on cells (t ppl d)

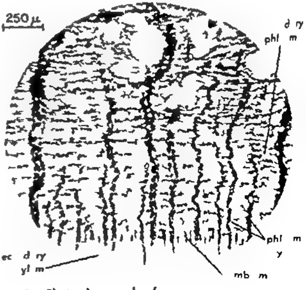
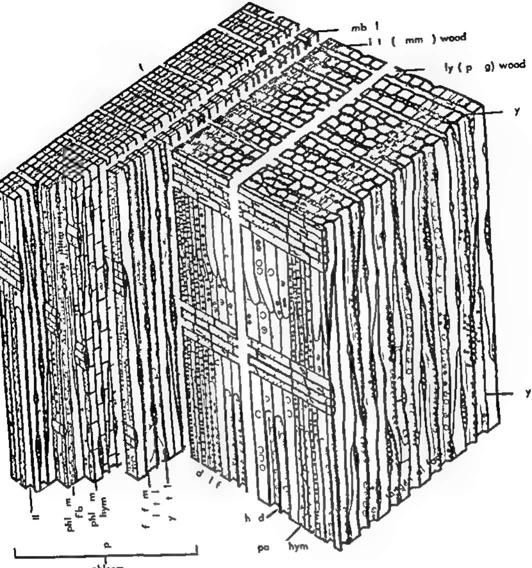


Fig 2 Phot micr graph f o s ct o of th sec o dary phloem f p p r b h (B t la papy fer) cl e to th amb al eg (F st P od t Labo a tory USDA)

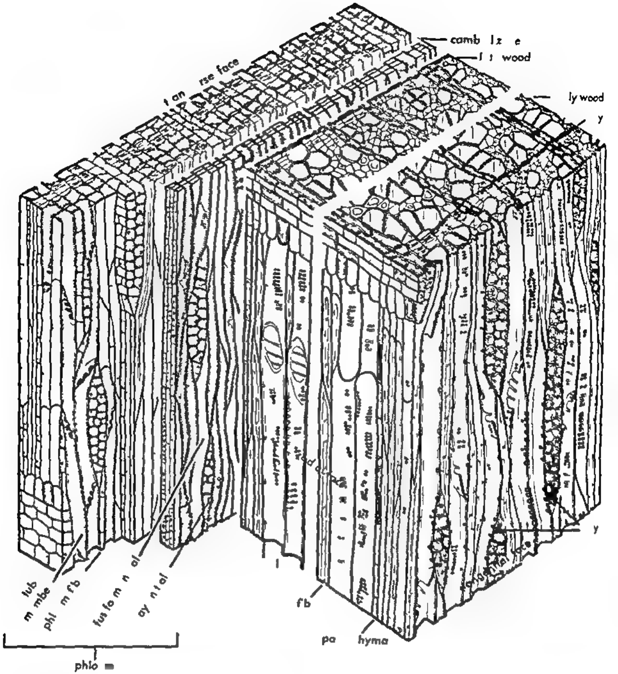


Fg 3 ... k d g m f th d ry xyl m m (gym m) Th j (wh t d) (C rt y f I W b l d d ry phl m f th f B l y)

b t m y m y t b l gn fied I e d ry phl m s me fib d t s e l gth be y d th e f th p m d b t th may l g t t ely by p l tr g wth f p m ry phl m mm t fib l ng t me t m h d ed f t mes th l l gth Th fib m y be m pt t f q tly mul t l t d m y t g d th l d (SCLE CHYMA)

Primary phloem P m ry phl m d ff e t t f m d t es f th p l m t m (s MERI F APIC L) Th l t p m y phl m (p o t phl m) t h fi l m t w th w th t mp ll d p h m ll Th el m t f t f b f t m d th bl t ted Th m g ll m b m ll hym t a m y l b t f m d t l p t phl m fib ft eo ly ll d p y l fibe (COLLE CHY TA PERICYCL) Met phloem is f med fte g wth l gth f n d g c lls s c mpl ted S e l me t mp ell (in a g p ms) d pa e h ma ll ch phl m b t typ c l fibe e g erally lack ng (s A GIO S ERM) If dary phl em s al t th m t aphl m f ct th gh t the life f th pl t

Secondary phloem S d y phl m p d ed by th m l ml m th t F m nd y xyl m (e MER TE I LATE L) S ch phl m t f tw te p net t g y tem th t l la d h t l y (F g 2) Th phl m y b all im la t ylem y but th c mp t ll d ffe n typ lly l k g ec d ry w ll M eo th g th f th t m oot i c th lde phl m ay ll w dth d m y d de d ll Th d l t ti d n t ll phl em y b t t i mm n f t f d y phl m



Fg 4 Block d agram of sec nd ry xylem camb al zone and secondary phlo m of the d cotyledo (ang pe m) L od d o (t l p t e) (Courtesy of I W Ba ley)

and stops only at the time of periderm formation within the ray The vert cal sy tem contain sie e elements parenchyma often fibers or sclereid and infrequently other elements such as laticifer (*see* SECRETORY STRUCTURES PLANT) The fiber may occur singly in di persed group or in tan gential band

Phloem of conifers The econdary phl em consists of long ie e cell parenchyma cell and frequently of fibers (Fig 3) The e cell may be arranged in regularly alternat ng bands that gi e an orderly appearance to the phl em as een in tran ection (*see* CONIFERALES)

Phloem of dicotyledons The phloem in dicoty led ns (Fig 4) ha greater di er ity of cell truc tures and of arrangement than that in the conifer (*see* DICOTYLEDONEAE) It is compo ed in varying prop rtion and groupings of ieve-tube member companion cell parenchyma ell and often of fiber clereids and ariou other kind of cell or cell group such a ecr tory The variou cell may be arranged in alternating band or have no regular patial di po it on The functi ning phloem i generally m re orderly in appearance than the nonfunctioning Thi difference re ult from partial or t tal collap e of th older ie e ele ments and a ociated c mpan on ell nd fre quently fr m the concurrent enla gement of neigh boring parenchyma cell S CYTOLOGY PLANT TI SUE SYSTEMS [V I C]

Bibliography See PLANT ANATO Y

Phlogopite

A mineral of the mica group al o call d ml er r bronze mica Its compo ition is K [Mg Fe(II)]$_6$ (Si Al$_2$)O$_{20}$(OH)$_4$ including min r am

od um (Na) that b titute fo p ta sium (K) and c ta n g sm ll m unts of Mn Fe(III) a d T W th an c e se i F (II) t gr de nto l tite fr m wh ch th e i harp di t nct on

Phl g pite s table at h gh r t mpe atu e a d h a h gher p er fa t r than m a ite w th bo t the am olt ge br kd wn It i widely u d i l tri al in ulato

It u s n d m ated fl k f l ated m o l rg ery t l The b al clea ge s ea y and p f t p cifi gr ty 28–30 h rdne s 25–30 Th l eets a tr par nt in sh d s of l ght b w d g e Reddish l r w efl ct ons re ch ra t i t c of l a e urfa es It m y be ol le t we kly pl cl o

Th tr tu s a e m ch ic (layer two-laye d three-l y r p do h mb hedr l) M ny phl g p t d pl y a te i m n t an mitted l ght b ca e f e t d l ed rutile ne dl

Phl gop te i curs ch fly i c rta n pe dotit (k mb lt) rpe t i ed p idot te m r bles d i ed f m imp e d l m t l m to and ry l rg ry t l f comm re l mpo tan e in a gr d pl g o l e patit cal te-py x ne rock f pegmat tic affi ity (Ont io a d Quebe) S e M ca SILIC TE MINERALS [E W H]

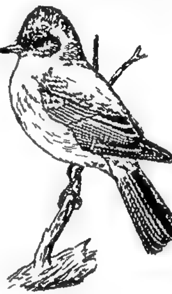
Phobic reaction

A typ f u o i Th spe fi f m whi h ph b t i te at l f who i ra t al ty th ndi d al m y eal with t b ng bl to d p l th f t If may t k a e almo t as d the h m n m n tio Th ha fte be l b l d t nd th m nt med ally c pt bl m ol gy f r xample ny tophob r m b d f i f d k h l ph b f r f d z ph b f of an m l my phob f f m nd tam at a ela tr phob a f a f b g n a f d pa e gor ph b a f a f p n pla e hyd ph b a f ar f water a d ph l ph b a fe f ph l s Th pec fic f may b d l r t c ympt m the th l t ly d et p tter l t d to p ti l p y h dynam f nd ti n d m y u th n the nte t f br d r p tte f m l d p-t be q it r d m t m s they i t t a g n r l d f a f a cla f bj t o member mpl wh h ld s b ti by a d g it m y learn m b dly t f ll d a Phob m tum s lt m e mpl mb l dd t t dd pla m t wh n f a f ex al p t n l ads to f f ll sh p bje t

Co t rphob t a e th n n wh ch th pe go o t of hi w y t m t th da l i r d ng mp l h d on as f n a ff t t ga n ma t ry by f t t f the d ng M fte tha n t th nte ph b ma e lf d f t g f th p s d ti g h s ff t t tow d h e p bl m b t t wa d m f gm nta pr t t n r m d pl ed of i Th d d l t of uch reacti ns often lead to a kind of l ro zation of the s ff rer prov d ng a certa n amount of ec nd ry ga n th rel y *See* ABNORMAL BEHAVIOR NEUROSIS [J S B W IS]

Phoebe

Any f thre spec es of flycatcher of the genu *Sayornis* all found in the United Stat The ea t ern ph e e *S phoebe* i the be t kn wn It ne t in utl ern Can da thr ugl out the United State e st of th R cky Mounta n nd uth to n rth rn



Th ph b S y ph b le gth i 7¼ i (F m E L P (m F ldb k f Nat al H st y McG aw H ll 1949)

G org Its wi tful call n te of pl oe be or pe wit ph b pe ted i and er and its hab t of te ter ng a t l wagging wh l lt ng o a l w p r h r adily di t ng i hi g tra t It nests and r m ll br dg nd other t uct s at ed a few f t f om th g u d *S e* FLYCAT HER PAS ERIFO MES PEWEE [J D B]

Pholidota

A d f m mmal wh h nclude nly the pa a h aly ant ter Thes t geth w th th a d ere lo g pl c d the s me o der w th th So th Am an ed nt t til i asing k wledg how d th t th y ar q ite d t nct F s s l pang l r pr ct lly u kn wn a d th an st y f the g o p th r f b u e Th l n a e n que am g m mmals in that th a d n rm of a lapp ng ho ny scale Hai s a e p esent a s parts of the bod e n b twe n the l s i As at c pe s Teeth e mpletely ab t th kull i elon g te nd th t gue w rm haped a the t ue m tes S sp es ar kn w f m t p l A a d Af ca ll r pl ed n the g us *Ma i S* F THE IA PHOLIDOTA FOSSILS [D D D]

Pholidota fossils

Fo il pangolins are repre ented by i olated bone from the Pleistocene of Asia the middle Oligoc ne of France and the early Miocene of France and Germany The e few fossils indicate animals imi lar to living form mall to medium ized large clawed quadrupedal arboreal or terrestrial mam mals with edentulou tubular skull well adapted for a diet of ants The most remarkable character of the living forms is the complete covering of large horny imbricating cales Pangolin ance try is largely conjectural becau e of lack of fo sil record but it may approximate the ance try of the order Edentata *See* EDENTATA FOSSILS

[D E S]

Phon

The unit of loudness level Although the ba ic unit of loudness is the one loudness level is frequently u ed The loudness level in phons of a sound is numerically equal to the ound pres ure level in decibel of a 1000 cps reference tone which is judged by li teners to be equally loud that is to *have the ame sone value* The relation between loudne s in sones and loudnes level in phons i shown in the accompanying nomogram The u eful ness of the phon as a unit is limited by the fact that the number of phons is not proportional to the ubjective loudne s of a ound as experienced by a li tener

A major problem in noi e control has been the evaluation of the loudne s of complex noi e For example the loudness of a noi e which contain energy in a number of octave bands is not equal to the imple um of the one value of the indi vidual octave bands pre ent in the noi e The loud ness in sones of a complex noise can be e timated with the aid of the following equation

$$S_T = S_m + 0\,3(\Sigma S - S_m)$$

where S_T is the total loudne s in one S_m is the number of sones in the loudest octave band and *ΣS is the sum of loudnes es in all the octave band*

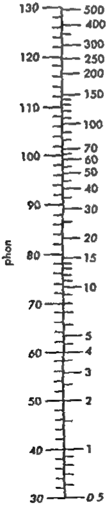
The loudness of a complex sound in sones can be converted to loudness level in phons by u e of the nomogram or by the formula

$$\text{Phon} = \frac{1\,2 + \log_{10} S_T}{0\,03}$$

The relation between the ubjective loudne of a ound and how noisy *it sounds to people* ha not been determined *See* LOUDNESS *see also* DECIBEL SONE

[K D K]

Bibliography S S Ste en Calculation of the loudness of complex noise *J Acoust Soc Am* 28(5) 807–832 1956



N mog om g ng the relat o h p betw n loudn ss o e a d lo dness l l ph s

Phonetics

The tudy of the sound which make up peech It includes the *production and reception* of the sounds their cla ification and li ting their ph i cal characteristics and the ariati ns of the ound among languages and dialects

A et of symbols to tand f r the ounds i re quired in writing For thi pi rpo e th lette i ed in Engli h pelling are nadequate Alth ugh they may g ve ome hint a to pronunciation many let ter ha e a numl e of different pronunciation wh ch are indicated in dictionarie by diacritical mark Other ymbol ha e l e n ad pted l y the International Phon t c A iat n The tal le li t 38 of the IPA ymbol witl Engli h w rd f r il lu tration Thi li t i adequate f r m t ige i Ame i an Engli h

S me oun l tl t are tl u ht f a in le un t are really combi ation Tl u tl ow l f my i a diphthong n tl e v i l l of tl e t l le [mai] Th ch of cl o e i [tʃ] n l tl j f j in i [dʒ] On tl e tl er l an l om c ml n t i f l tl r are single n l l ke l [ʃ] tl [θ] [ð] an l n [ŋ]

In a language ther than Engli l me f th und in the tal l ill l r t i d m dr pped and n w ne ad l l F l n l l f tl tal le repre ents a pl neme tl it knd l th e t ing th l ngi ag a tl e i ut lth ugl it n v l e pr u c l i ligl tl l ff it wa in different c ml inati n r l y diff r nt p i l Tl l ght ariati n in pl n n ill l ll phon Internati al P l n ti Syml l l a i ad pted (ome a atta hm tl y

t m ton l Phon tic A soc t on ymbol

	V wel
meet	ɔ all
ɪ h t	t
h te	boot
t	ʊ foot
æ h t	ʌ up
k	ə bo t
ɑ f th	ɜ b d (Ea t n p at n)
ɒ sorry	ɝ l d (G l Am n n pro ti n)
	St p consonants
p pt	b l t
t t	d d
k p	g g p
	F ical c ns nants
f f t	v t
θ th n	ð th n
s see	oo
ʃ hed	ʒ
h t t	
	N l cons nants
m m	ŋ ng
n	
	Gl d s m vow ls
w w	red
j yes	l l t

th t l l l uffi e t to ndi ate alm t ll pronun at n th u l g ge A peech utt r w itt n thes s mb l e lled a ph neti t pti n

Th l fi t on u ed the tabl s a e rd to th alm thod f p d t f th nds Th t es m s be bd d d th u d m y be dif f tl l fied h ced (h t n f m the l rd p es nt) o n ed (only the f t l f haled p t) Conso nt m y be l fi d d t th l at n of n tr t h a bil b al (p b m w) lab od tal (f] d tal (θ ð) alv ola (t d r l] p l t l (ʃ ʒ j] l (k g ŋ) a d glott l (h)

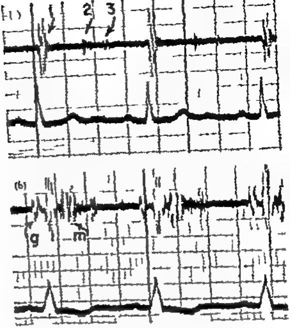
A p l nd m y b n l d t a fe q p t m wh h h w tr t ns f g t f q y alled fo m t f th d Th tech q k n v ble h h w n tl th t n f m t n f fo m nt f m nd t d ı m t l ght n g

l S SPEE H [H K D]

B bl ph C E Ka t e d P W t *Ph* t 1931 R K P tt G A K pp a d H C t *bl Sp h* 1947

Phonocardiography

Th l g aph l zat d ı t tp tat f d l t n so t d w th a h h t h t Th ph a d gr m s th ord l t d th ph d g pl th c d n t m t Th l t g n lly t of n a d mpl fi pled t a c bo cr t l p t n m ph pla ed th h t Ba d p filt m be pr led t ll w f n t



Fg l Ph d g m ( ) N m l s bject c rd f m c d c pe fi t (1) d d (2) h rt s u d pp pl t f t th d (3) h rt o d is p t (b) Ab m l ph oc d og am fi t d d h art d s t (a) The f t o d p c d d by t l g ll p nd (g) d g w th t l act ly s e f m the l ct d g m Betw n th f t a d d d p d g f b t (m) h t t of y t l m m S m lt el ct o- d g m b l w h u d d T me l q 1 0 04

th a cult tory phenomena of the hea t into va ı s f equ n y ra ges

Th ph nocard ogram are u u lly photograph um g of gal n met r defle ti ns illo c p c t a ı g o a time mpl t de l (*see* RECORDI G INSTRUM NTS GRAPHIC) F t mi g purpo e pho ocard gram a ge ally re ded s mul tan ly w th a pul e re o d r n electro ard o- g am (Fig 1) R co d ng te h que ge rally fol l w the ta dard pract e of cl n cal a ultati n ly mpa ecord bta ned fr m sp c fied ch t po t o s Fo m re det l d an ly s ph no d gr m h s n obt n d f m th r eas u h th e phag the a t of th h art d the l rg bl od l by m n of p cial ph ath t ad ced int the h rt thr ugh th u y t m pro edu e k wn a ntra r d a ph n c rd g phy Th m n tu m r ph n s pla d n th t p f th cathet a ba um t t ate tubula l m t r l ted t hyd ph n s d ı na appl tion (s SONAR) Spectr l pl n ca d gr phy s an d pt tion f the P tter nd p t ogr ph wh r by f q ncy t me a d l due f h a t n e n l d pl yed ı g phi f m (F g 2)

Mo t f th v brat n l e gy d loped d ng th h arth t l e b l w th f q y th e h ld of th hum A m ll fra ti n f th nergy

These are of low intensity with fundamental frequencies of 40–200 cycles per second (cps) with occasional higher values. Overtones and harmonics can be heard but these are attenuated during sound transmission through body tissues and are usually filtered out by the recording devices. For a sensation of equal loudness the human ear requires greater energy for low than for high frequency sounds. For this reason almost irrespective of frequency, heart noises remain consistently at the lower threshold of hearing (Fig 3). In addition, external noises from the room and street decrease sound perception of low intensity sound and in heart sounds with mixed frequencies the simultaneous presence of relatively loud low frequency components tends to suppress perception of higher frequency. These phenomena are of obvious clinical importance and are termed the masking effect. These characteristics of the human ear are not shared by a microphone-amplifier system. Phonocardiograms therefore cannot be considered faithful graphic reproductions of sounds as perceived by a physician through a stethoscope. A logarithmic phonocardiograph has been described which more nearly records the heart sound vibrations as perceived by human subject.

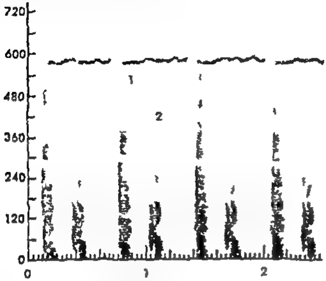


Fig 2 Spectral phonocardiogram. Frequency time plot. Intensity of sound proportional to darkness of the tracing. Normal subject recorded over region of pulmonary artery. Note splitting of second sound (2). (From V. McKusick, Cardiovascular Sounds, Williams and Wilkins, 1958)

Clinical practice distinguishes heart sounds from heart murmurs. Physically they are differentiated only by duration because both are irregular sound mixtures of low frequencies and variable intensities. The normal heartbeat is associated with two loud heart sounds occurring at the beginning and at the end of muscular contraction or systole coincident with the closure of the heart valve. In young subjects a third sound of low intensity is commonly heard shortly after the second sound and a fourth sound is occasionally present preceding the first

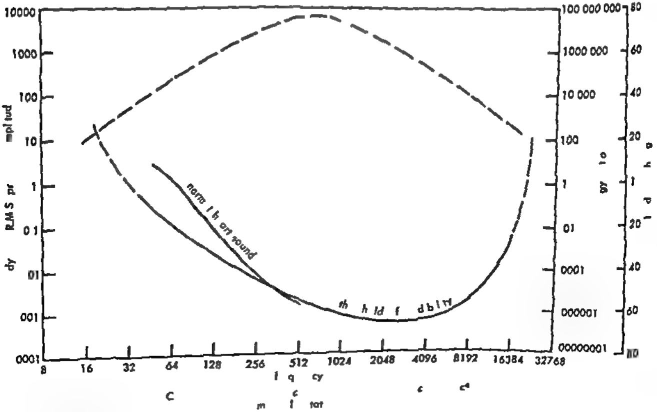


Fig 3 Normal heart sound and the characteristics of hearing. The range of human hearing is indicated by the curved lines with higher sound intensities required at lower than at higher frequencies to give the sensation of equal loudness. Intensity and pitch of heart sounds always close to the threshold of audibility (From H B Williams and H F Dodge, Arch Int Med 38:685, 1926)

s und a d related to the c tract on of the atr a Th e add t onal ound may bec me accentuated n heart f ilur in any age nd tog ther w th the fi st and ec nd sound may g the appearance f tripl or q adr ple hythm kn wn gallop th thms A vnch onous nt i ular ontraction val ar owing and extraca d ac adh n may g ri e to dupli at on of heart unds l cks and r tches of brief duration Heart murmurs may o cu a the c equen e f rap d bloodflow n an otherw e n rmal heart Th e ar known as flow *murmu s or eject on murmurs* r th y may h as o-iated with al ula and other structural intracar *d ac defe ts* Th techr iq of l m al auscultation upplemented by phonoc rdiography is co cerned with de t fying pitch (f eq en y) intensity tim i g d r tion and max m m ar a of tran m s on f ound and m rmu s w th pec fic tru tu al chang with p and al o t the h rt

The phy cal b si f r the orig f he t n nds a d m rmur is la gely p culati e In a clo ed fluid compartm nt u h as the va ul r sy tem the r l f s und energy equ e turbulent flow with ddy or vort x format on can ed e ther by ex c i p d of fl w or by n rmal r pathologic ob truction re lt ng in s dd n ch ges in bl od lo it The c xrren e f h gh f eq en tran nts and of murm rs th tonal (mus cal) qual ity sug ts that unde pathologic rcum tan e ol d tru t re with n th heart may be et in i b at on gi i g ri e to ab i rm l no Th f rma io and ollap e f po r g p k t (c ita t n) oc ur g in lo l a ea of h gh locity has l b e la med as a sou ce f r p th logi o nd S BIOPHYSICS ELECTROPHYSIOLOGY

(HE RT) [H HE]

B bli g aphy V M K i k *Ca di s l S d* 1958 M B Rappap rt H B Sprag The gr phi reg t at on f th norm l heart u d *Am H t J* 93 591 1942 B Rodb d (d) *Symp s m Pr se t Status of H a t S d Pr d i a d Re ord ng* IRE T ns on Med Elect o PGME 9 De ember 1957 H B W l lams n l H F Dodge Analys s of h rt und *Ar h l t nal Med* 38 685 1926

Phonograph

An n tr m t f rec d ng (ep d ng) a us-t al g l uch a v ce and mu i by t an m s-f ib ation from (t) tyl s that i n n ta t w th a g ove n r tating d sk F r n ev t nded d uss n f ph nogr phs ph nograph r o d and related t p c ee DISK RECORDING

[R F D]

Phonolite

A l ght-c lo d, aph n t c (not vi ibly cry tall) ock l ol an r g n comp ed la gely of alk l feld p r l ld p tho d (neph l e, leu te da l t i nd malle mount f d k colo d (mafic) m ne l (b ot te od amph bol a d oda py x ene) Ph l te hem lly th effu eq a lent of n ph l ne y t and s m la r ks Ro k in which plagioclase (ol gocla e r andesine) ex e ed alkali feldspar are rare and may be called feld pathoidal latite *See* FELDSPATHOID

Rapid cooling at th urface cau s la as in solid ify with ery fine grained texture Mo t phonolitic lavas howev r carry abundant large crystals (phe noc y ts) when they ar erupted and these are oo f oz n int the de matrix to g e a porp y ritic texture Gener lly ery little material c ngeals a gla The phen cry t many i ible to the naked ye include lkali feldspar feldspathoids and mafi s These m y be well formed (euhedral) or moderately well formed (subhedral)

M st other fe tures of phon l i can b een only m c o c pically The alkali feld par is princi pally soda rich sa idi e and orth cla e It gen rally occu in th rock matr but if abu dant it may also fc rm as p heno rysts Plag ocla e is not abun dant except in n ph line latites whe e it may form abunda t phen crysts

Nepheline m y occur as euhedral cry tal (squa e or hexag nal) ome of wh ch may l e phe nocrysts Otherwi e it is irregular (anhedral) and nterstit al No ean hauyne and sodalite a euhe d al or pa tly corroded c y tal may o cur a phe nocry t a d mat i g a s The e twelve sided (do-de ahedral) cry tals generally how hexagonal outl nes in th n sectio s of th ro k E ght sided e h dral crystals of ps udoleucite may occu in phe ry ts in pota h r ch r cks More rounded gr ns of leuc te may form pa t f the matrix Leu cite commonly altered to ps ud leucite b t the euh d al outline s ret ned Anal ite o curs prin cipally a mat ix material but in s me r ks it is abundant and as large e h dral pl enocrysts

B ot te i n t common but may f rm l rge st ongly eso bed phen cry t Amphibol a e usu ally oda ich (rieb k te ha t ngsite and arfved s n t) They may o cur a phen ry ts or as inter titial l te s They m y show so ption or may be replac d by pyro n The m st import nt mafic i soda pyr n A ph ocrysts t i ommo ly zoned with core of d op de surr unded by pro-gres i ely m r odi shell of a g ine augite and aegir t A g r t is th c mmon pyr x ne of the r k mat x

Acces mineral a ed a d i lude sphen m gnet te z on, nd ap tit

Th struct es nd t xt re of phonol te are s mi la to those f the m re comm n rock trachyte Fluidal t u tu e form d by flowage of solid fyi g l va nd xpre ed by lines o trails of phen crysts m y b see with ut magn fication Under th mi cros op flowage s hown by subpa allel ar nge-ment f elongate feldspar crystal *See* TRACHYTE

Phonol tes are ra e and h ghly ar ble k They o r l an flows nd tuffs d a small tr si bod s (d k s and sills) They are as o-iat d with t hytes and a w de ar ety of f ld spatho dal rocks

The origin f phonol tes and r lat d r cks o stitut s an t est ng pr bl m There is still o s der ble diff ence f n n n t heath

liti magma (molten material) originates One theory assumes an origin from ba altic magma l y differentiation Certain early formed cry tal are removed (perhaps by ettling) cau ing the re idual magma to approach the compo ition of phonolite Another theory uppo e these peculiar magmas to form when a more normal rock melt a similate large quantities of lime tone fragment Volatile notably carbon dioxide are considered by many to play an important role in transferring and concen trating certain constituents (like potas ium) in the magma The great variety of rock types and modes of association strongly sugge t that everal differ ent mechanisms may operate to form these feld spathoidal rocks *See* IGNEOUS ROCKS MAGMA

[C A CA]

Phonon

A ound quantum The energy of a phonon is $h\nu$ where h is Planck s constant and ν the frequency of vibration of the ound wave The phonon is thus analogous to the photon a light quantum

In treatments of the cattering of electrons and other particles by thermal waves (hort ound waves) in matter the election rules which ari e bear a formal resemblance to the laws of con erva tion of energy and momentum holding for colli sion between particles This lead to the concept of a phonon as a packet of ound wave the wave packet having particle like aspects The concept i particularly convenient in the theory of the thermal conductivity of insulators where one may peak of a phonon gas collisions between phonons and a phonon mean free path In the theory of the prop erties of superfluid helium the quanta of longitu dinal sound wave in the liquid helium are called phonons *See* CONDUCTION (HEAT) [J D L]

Phonoreception

The perception of und by animals through pe cialized en e organ A en e of hearing is pos e ed by animals belonging to two di isions of the animal kingdom the vertebrates which form the main subphylum of the phylum Chordata and the in e ts which compri e the most important cla of the phylum Arthropoda This en e is mediated by the ear a pecialized organ f r the reception of vibratory timuli Such an organ is found in all except the m t primiti e vertebrate but only in some of th many pecies of in ect The verte brate and in e t type of ear differ in evolutionary origin and in their m des of operation l ut both have attained high le els of performance in the reception and di criminati n of sound *See* SOUND

Vertebrates The vertebrate ear is a part of the lab rinth located deep in the bone or cartilage f the head one n either ide of the brain A c m plex a embly of tubes and chambers co tains a meml ranou structure which bear within it a numl er of n ry ending of different kind

The membran i labyrinth is h wn in a g ner alized chematic form in Fig 1 It is convenient to recognize tw di i ion a uperior di i n which

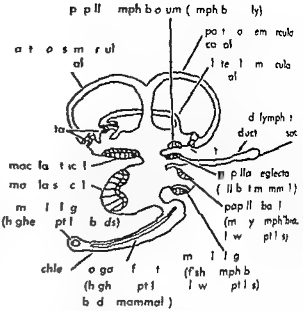


Fig 1 Gene al zed sketch of the verteb ate l by nth The th ee stae macula ultricul d macul socc l are alway present in ve t brat s and the othe e d ings appea a ind cated w th a few e c pt ns

includes the three emicircular canal and the utricle and an inferior divi ion which include the saccule and its appendage the lagena and the cochlea The superior di i ion i remarkably uni form in character from the higher fi he i ward but the inferior divi ion ho s many variation The saccule is always pre ent The la ena i present in all clas e except the mammal although it i mi sing in occasional specie The c chlea i found in reptiles bird and mammal

The ensory end ngs within the e parts of the labyrinth al o vary in the vertebrate erie Again there is uniformity for the superior divi ion There is a crista in ea h ampulla of the three emicircular canals and a utricular macula In all but the mam mals (with a few ndi idual excepti ns) there i a macula neglecta u ually lo ated on the floor of the utricle or close to the junction of utricle and saccule All f rms ha e a accular macula All those with a lagena (in general all except the mammals) have a lagenar ma ula All the am phibians have a papilla amphibiorum but it i found in no ther f ms A l a ilar papilla appear in certain ampl il i ns i ontinued in the reptiles and then is de eloped in m re elal rate f rm a the cochlea of higl er pt le b rd nd mammal

The endings c ntain iliated ell (hair cells) which are supplied l y fil ers of the eighth cranial (auditory) nerve In th r tae th ilia f the hair cells are parti ularly l ng an l re eml edded in a gelatinou ul tan e that f rm a c p l cupola In the maculae th ilia n rm i nt d by a flat plate of gelatinou m ter l in wl i h numer ous granule of cal i um rbe nate (t l th) are u ually eml edded The cil ated ll tl papill lie on a m val le m ml rane (l a lar m ml rane) and h e a meml r n co g the t rial m ml ran

Th upe r part of the laby inth g nerally rı f r b d ly p t re and equ l bri m wh rea he c l nd ıt app nd g (lagena cochlea) er f r h a ng H wev the e ar ex eption thu rule th mo t mpo tant of wh h ı that n tle bigher teb ate ı clud g m mmal and pr labl b d and r pt le the ceule erve only f r q ı l b ıum *S e* EQUILIBRIUM BIOLOGICAL

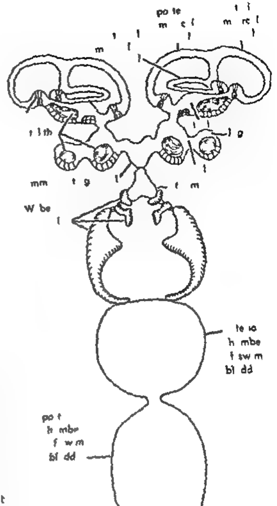
B g nn n w th the mph b an whı h ar th arl t e tebr t t pe d a n d abl ı o t n f th r liv n l nd th r appe s a p c al m han n tle m ddl e r who f n t o ı tle tr n m ı n f aerial v brat ons to the d n s of th nne ea All the erteb at s bo e th fi h and certa n f the fi hes well ha e som typ f ound f ılitat me han m

Fı h s Th ma ul of the ut cle acc le and l the bony h he ha e a p ul a f rm In tead of mer u cal ar ı rt cle the e s a s ngle tol th a large body f d t n ıı e form Th m cul negl cta ı m t m s la king

F w qu t l a e b n m re cu ely deb t d than th ab l ty of fi l to hear Expe m nt n th q e t be n w th G P h r 1903 who b rı d th at l r a t n of fi h wh n xpo ed t udd n u d and were ca ed f rward by F W te fi ld and th r n 1922 by th ntr duc t f nd t ed r po e method Th work culm n ted th e es of tud l y h Fr h d h a ı t wh tra ed fi h t make fe d n p n e at it und ng f t n The exp rı me t p o d th t fi h m b d ıde l nto t gro p a o d ng t h ın ab l t th e th t h a only d ly and th th t h r well Th fir t gro p n l d tle g eat aj rıty f fi h p c w th hat ma b all d th ba t pe of l by ınth d l ck ng any a e m han Th fi l tl t h r ll ha e f tw g ne al types of und f ıl tat ng tru t e ther a a vesicle dja nt t m pa t f th lab ınth a onn t n w th th w mbl dde

Th e ond f th t p f a ce rj t t the m r e mm n and f und n a l rg g p of fr h w te fi h s k wn a the O t r oph st B t n the labyr th nd th nt ı ıart f th ıml la ld a ha f th fo m ll b es kn f m the d v r r E H Web ll W b a sı l (F g ı W l e r tlv p p l h n h d l d th pp rat s 18 ll th t t rı f th f c l t t of d c pt n f ıt h be d n t ated that th h ar ng s mpa ed fı emo l of the wimbl dde d alı r nt pt n l the la ch ı

Th m t ten tudy f h ar ng f h h leen m d n th F p an m n w (*Ph xı s f* f f th O t ı ph that p d ead) t t a ng pr d Th fi h ı al l t t ı n r a nge fr m 3 ycl pe d ı p) ltıl l l w ı 5000 6000 p d ı th l r pa t f th a ge d e m at h g f lr q n y f h t 3ᶜʳ The dw rf at fi h l ı l (*Am t usl* *b l us* respo d t t nes a h gh a 13 000 p



F g 2 Th tw loby ths of a o to physon f h d th ct w th th w mbl dd ı th gh th W b cl D og mmat c w f om b

F m rmy ds and labyr thin fi hes wh ch ar fo m with an at e ı l adja nt t the labyrı th the ppe l m t f l ea ıng s ar und 3000 cp In o d a y fi l (wh h la k the ce n y me han m) th l m t n ally fo d b t e n 600 and 800 p and the en ıt ıty ı 30–40 de bel (db) poorer th n th O ta phy

A numb r f exp e ıment m tly *on* m nn ws have dealt with the p ol l m of th pa tı ular part f the fi h labyr th that a n nce n d w th h ar g Remo al f th per r p rtı n which ın l d the utricl a d cmı c ı l r an l d s not mpaı th respo es t ou d but r l y affects the p t e n l wimm g b l t Afte th p r t on th fi h m y um an rted p s t n and w ms at cally The pa ts mu t th f con t n ns f q ıl br m R mo l mpa ment of th r th a c le alon th lagena alone l a s the fi l ble t he c h t th emo al f both a c l nd lagen aboli h s th e pon e t all to s ex pt tho e f ry low freque cy wh h a

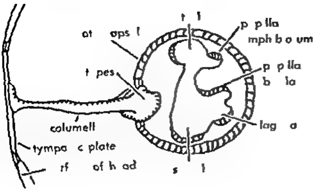


Fig 3 Ear of the frog Diag ammat c s mpl fied

perceived through skin receptors Hence the endings of the saccule and lagena are auditory in function Exceptional in this respect are the herring and sardine (clupeids) in which an air vesicle is applied to the wall of the utricle in these the sense of hearing is probably mediated by the utricular macula

Amphibians The three orders of amphibians—the Apoda (legless) including wormlike forms such as caecilians the Caudata (tailed) including mud puppies newt and salamanders and the Salientia (tailless) including frogs and toads—all have some type of middle ear mechanism

The fir t two orders include animals whose ears show a great variety of accessory structures ome of which look as though they might function well in sound rec ption whereas others seem crude Of the e only the alamander has been studied experimentally In 1938 S Ferhat Akat trained larvae to come for food at the sounding of a tone and got results for tones up to 244 cps in one specimen and up to 218 cps in three others

Higher amphibians such as the frog possess a well developed middle ear mechanism consisting of a disk of cartilage flush with the lateral surface of the head and covered with skin and a rod of cartilage and bone called the columella leading inward from the disk and expanding to form the stapes which is imbedded in an opening (oval window) in the wall of the otic capsule (Fig 3)

The active and often loud croaking of frogs in the breeding season has focused attention upon the problem of their hearing R Yerkes in 1905 first succeeded in obtaining experimental evidence of their auditory sensitivity by showing that ounds may enhance or inhibit their response to a strong tactual stimulus Several studies in which the impulses from the eighth nerve were recorded on stimulation with tones showed results only for low frequencies up to 500 or 600 cps or at most to 1024 cps The mo t extensive study of the electrical respon es of the ear b W Strother in 1958 showed re pon es in *R a catesbeiana* over a range from below 100 cp to about 3500 cps The ensitivity wa be t at 400–1500 cp and then fell off rapidly t the upper limit

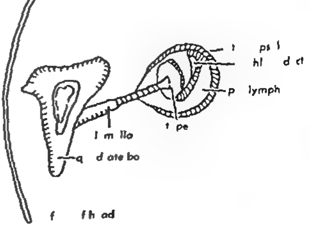
Reptiles Th living reptiles belong to four important groups repre ented by snakes turtle chameleons and li ard and crocodile and alligators

Many authorities have as erted that nakes are completely deaf or that their ears are en iti e only to vibrations conducted to the head through the ground Thi impression has ari en partly from the fact that snakes do not have any external ear and do not show obvious reactions to ounds There is no tympanic membrane to recei e aerial ound pressures but its purpose is erved by one of the bones of the skull the quadrate bone which is loosely attached to the main part of the skull Although it lies beneath the skin and other ti ues of the side of the head the quadrate bone pre ent a flat surface for the action of sound and communicates them to a thin bony rod (columella) running inward to expand as the stapes in the oval window (Fig 4)

Recent experiments have shown that electrical potentials are produced in the inner ears of nakes in response to low frequency sounds to both the sounds conducted through the substratum and those conducted through the air in the u ual way Hence it seems saf to conclude that snakes have hearing although only for the lower range of sounds and not as highly sensitive as that of most other animals

Doubt has often al o been expressed about the ability of turtles to hear but here again the e i dence is that they do They have a well developed middle ear including a cartilaginous di k on the side of the head beneath the skin and a columella leading to a stapes in the oval window of the otic cap ule Two investigators have succeeded in training turtles to make positive reactions to an acou tic signal although others have failed in this attempt The electrophysiological method yields positi e results Indeed the observations show that for low tones those of 100–700 cps the turtles have excellent sensitivity with the wood turtle *Clemmys insculpta* exceeding other species studied (Fig 5)

Structurally the ear of the lizard is superior to that of the turtle There is a membranous drum a columella and a stapes A few studies have dealt with their hearing and there is no doubt that they hear sounds in the middle range of frequencies



Fg 4 D ag m of th of a ke Th o d tory part a d d gs a t h w

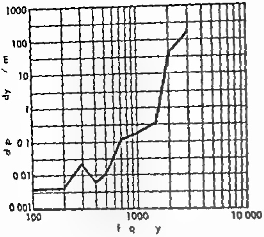
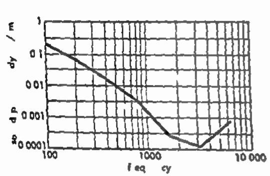


Fig 5 Th d t ry t ty of wo d turtl Cl mmy lpt h w by th pot t l p o- d d t by d Th rv h ws th d p ry t pod p t t l f 0 3 m c o olts



Fg 6 Th h t ty th b llfi h (m of 4 b d) (F m J S hw rt k pff Db S d L s- f g G h d V b lo b V g l Z gl Phy l 31 527–608 1949)

C. B g r w bl t tr two pec es f h rds (*La t g lis* a d *L t p a*) to m ke fe di g m mnts in re p n e t a u o d n ludi g t n o e r nge f om 69 t 8200 cp Fle t al pot t l h bee re ded f m th a s of th l zard *A lt f t* the a f 100–10 000 p

The d l h an e r repres nti g d s- t t ad n th ept l nd th e a c rv d hl a m l that f b d Pr bably th h x ll t h a t g lth gh the xpe t m t l e d s a ty y t M g ne al ob- rv t n d te th t they s u d m ting t t d th male re ap bl f p oduc ng lo d F B h was ble t p o ke m l t a t g nd mak g m m nts by t m lat w th low t n s pe t lly ou ds at 57 p b t l th t bo t 300 cp E Wev a d J V fo nd th t yo ng c ima s g e co hlea p te t l n p n t s und e a ra g of 20–6000

B d Th l by t th n b rd t ge e lly m l t th t f th h gh ptil The e s m mb n u drum a c l m ll le d g t wa d t th t pe a d a ct rved c hle There are only minor ariat ns n the form f these tructure among the o s pe ies

Mo t bi ds ha e a range of hear ng of ab ut 50–20 000 cp nd n al of te it ity that prol a bly ppr acl e th t f man in the med i m high t e range The th e h ld en iti itv f a fncl *Py rh la p mi or* s h wn in Fig f a determined by J S hwartzk pff by a training method In g n e al the m ll ngb rd are more en itive than the lar r b d ch a chicke and pigeon Tl e owl s excepti nal in ha an ear with a particu larly l rge drum membrane and other pecial fea t es th t make for high en iti ity Thus a wl p rched in a t ee at d k t al le t h ar and t lo ate a m u e ru tling in the gra l el w

P tch di cr minati n in ngbirds and p rr ts i b t a keen a that of *man* (0 3–0 7%) b t geo s it is relati ly poor (6%)

M mmals The a ditory apparat atta ns its l ghe t de el pme t in the mammal The c l m ll f l wer f rms ha b n replaced by a chain of th e cle which conne t the tympani m m b ne w th th in e ear In the egg laying mam m l u h the platyp the c chlea i a irv d t be in e cod les and b rd l t in all ther mamm ls t s a pi al of 1–4 turn The g eat ex ten n f the c hlea nd th r pond ng m l tipl cati n of n o y cell ha e e h need th ca pa t s f th m mm l t d al with the va i tie nd mple it e f und

D pte t n e nte t in mammali n h ar ng p ec inf rm t n is a ailable n o ly a few mam mal pa t fr m man him elf Exper mental tud ha be n a r d to om of tl e u h man p imat s nd a few f the c mm n lab rat y a m l O ly fr gmentary i f mati n av l l on the ma y other pe of mammal al th gh it an b umed from tl e r g n ral beha be au e they s em t re p nd t m ch the same a ge a d inten t es f und that man d es that th r he ng is similar t m n

Tr ni g xpe me ts e e ly c rri d ut o the a bb m n p im t and F pr e ts th e h old urves f r th ch mp nze tl e th u m ke and a spe i of marmoset with th huma urve f r mpar s n It w ll b noted that the e ani mal h e ud tory en t v ty mil r t man in tl low t ne ng t ar s pe ior t m n in th h gh t nge

The m t e ten t des h e b en mad on the c t It s t ty al is s mila to man s o the l we r nge t e t nds fa abo e th human l m t to 60 000 ps mo El tri l pot tials ha be n re ded f m the at s ochl a to tones s h gh 100 000 ps

Othe n m l who he ring has b e studied r me t lly a e th dog r t gu nea p rabb t c rtain p cies of m ce nd bats

Tl t of pe i l inte e t m particu l rly th mall n t v ro pe e b cause th v r peat dly p d e or I s und f h gh f equ n y p t 40 000 p as they fly bout in e r h f e t p ey They l t the p ey by hea g the

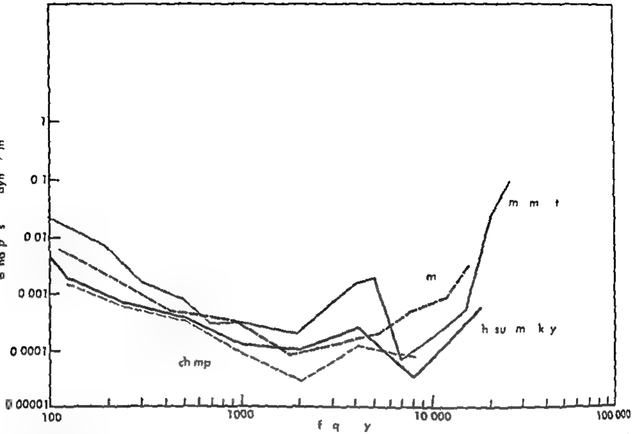


Fig 7 Auditory thresholds in primates The curves show the sound pressures that are barely audible for man chimpanzees rhesus monkeys and marmosets (Data from S an and Wh t Elde Har s We d and Se de)

echoes of their cries Similarly they guide themselves in the total darkness of caves by echoes from the walls The hearing of bats extends far into the high frequencies up to 100 000 cps at least See EAR HEARING

Invertebrates The group of invertebrates which has received the most attention has been the insects Other arthropods such as certain crustaceans and spiders have also been found to be sensitive to sound waves

Insects The insect ear consists of a superficial membrane of thin chitin with an associated group of sensillae called scolophores Such an apparatus is shown in simplified form in Fig 8 These ears are found in most species of katydids crickets grasshoppers cicadas waterboatmen mosquitoes and nocturnal and spinner moths They occur in different places in the body on the antennae of mosquitoes on the forelegs of katydids and crickets on the metathorax of cicadas and waterboatmen and on the abdomen of grasshoppers Probably these differently situated organs represent separate evolutionary developments through the association of a thinned out region of the body wall with sensillae that are found extensively in the bodies of insects and by themselves seem to serve for movement perception

The instruments described above are noted for the production of stridulatory sounds made by rubbing the edge of the wing together or leg against a wing These sounds are produced by the males and serve for enticing the females in mating

The sensitivity of insect ears is keenest in the high frequencies Figure 9 shows threshold curves obtained on a katydid by observing the potentials produced in the auditory nerve during stimulation with sounds As will be seen the sensitivity in this species is greatest in the region of 7000–60 000 cps It extends to even higher frequencies usually as high as 120 000 cps and sometimes beyond Other species have distinctly different sensitivity curves and there is reason to believe that there is a relation to the range of the stridulation sounds There is evidence that these sounds are discriminated for

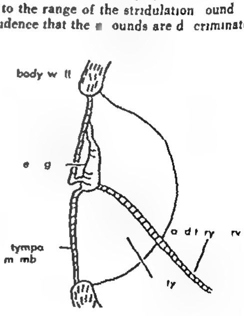
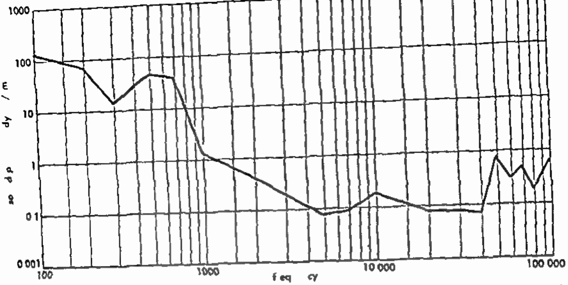


Fig 8 Ear of a grasshopper diagrammatic



Fg 9 A d t ry th h ld f th k tyd d C ph Th d t ry t ty of O th pl P N tl I st ct (F m E W d J A V A d S 45 413–419 1959)

th femal f o e species e po d to th mal s f th w kt d J Reg pl c d ag f h rp ng mal r k t t a fi ld and f d th t f mal f th sp es ght them t Th ek g ti ty a d h we e when th male we e d p ed f th t d l t g o g n r tl fe males w m d deaf by em l f th ea A m t t k g d pt t on s that sh wn by mo qu t the e r of the m l mo q it is en ti nly t w ge of f eq e s ar d 380 cp nd th f q e y the ne p d ed by th w g of th f m l in fl ght M Ti hne fo d th t wh th e of a mal m qu t w s made n fun t l the m sq t fa l d t find a mate

[E C W]

B bl g phy F Egge *D n ftj h de S g* 1928 K v F ch Über d n Geh d F h *Bi l R* 11(27) 210–246 1936 *D R G fi I st g th D k 1958* J Schwart kopff Üb S t d Le t ng G h d V b to n b V gel *Z gl Phys l* 31 527–608 1949 E G Wev r d J A V n The d t ry en t ty of Orth pte a *P A tl A ad Sci* 45 413–419 1959

Phoresy

A l t h p b tw two d ff r t p f r g m wh h the l rge o h t g m t p rt m ll g sm the g t It i ded typ f mm l m wh h th e lat h p l m ted t t p rtat f th gu st Th t m ed t d t P L f ll wi g h b erv t n th b l gy f m ll fly *L m* whi h t po t d by b d f th d g be tl t t b rr w Th b rr w e t bl h eed g t f both im l

[C B C]

B bliog phy P Les Moe d *L w a* M g Ph n m es d t p rt m t l ch les A imaux rt ules O ig s du ja a ti m hez le I tes d pt re *B ll S c Ent Fr* 162 165 1896

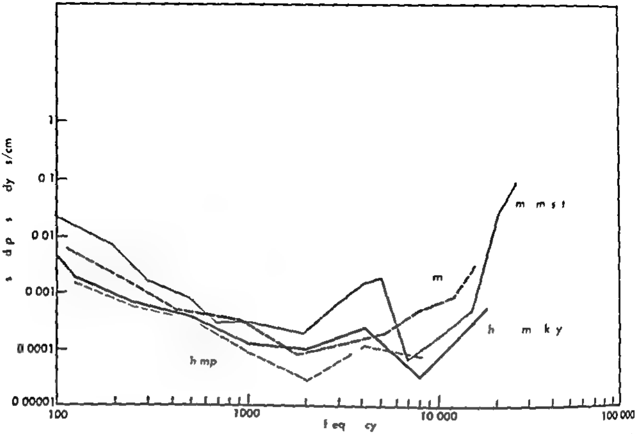
Phoronida

A small rel ti ely hom g neous gr up f an mal w ge rally n de ed t o tit te a p rate a im l phyl m alth gh n the p t they ha b n gr ped w th ther phyla u h a th An e l da M llu idea nd Ch rd ta Tw gene *Pho nis* and *Ph o p is* nd abo t xteen pe c s re ecogn d at th p es nt tim h we er the t x omy of the g up is ne d f th o gh revi on

Habitat and distribution I h id may occ in erti l tub s pl ced ju t bel w tl e rfac in i t rt d l btidal mud fl ts r a feltl ke ma s of tertwi ed tube att hed t r cks p l g o old l g t sh llow wat *In b th c the t b* mp d ba i lly of s ted n hmentl ke mat al e encru ted w th m ll part cles f s nd n hell A tl d l ng hab t cerns tho ph ro n d f nd n d h els p b bly lf mad i l m to e o k the hell f de d pelecyp d m ll ks

The ge gr ph cal d st ibut f ph ds ap p r to b w rld w de t mp t nd tropic l e s Th n c d f m th p lar on

Morphology Th b dy i m r r les elo ate ang g l th fr m ab ut 4–20 *cm* a d be a wn of t t ele a anged i d ubl ow u d g th m th wh ch s ll r e t haped The an s o t th l l f th m th d b n p lla immed t ly ts d th d uble w f t nta l Th d g ti e t a t i the f r U h ped th m th d n pen g l t g th at d f th a imal Th t ta cle e t o a necti t b k wn th loph ph (LOPHOPHORE) Th d ble r w f



Fg 7 Aud tory th e holds p mat s The c rve show the s u d p s u s that a ba ely a d ble for man ch mpa z es he s m keys and ma mo ets (Data fr m S v an a d Wh te Eld Har We dt a d S de)

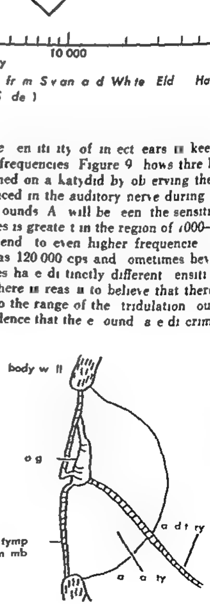
echoes of their crie Similarly they guide them el es in the total darkness of caves by echoes from the wall The hearing of bat extend far into the high frequencie up to 100 000 cps at lea t *See* Ear Hearing

Invertebrates The group of invertebrates which has received the mo t attention has been the in e t Oth r arthropods uch as certain cru taceans and piders have al o been found to be en itive to sound wa e

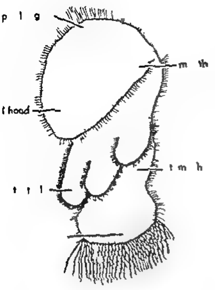
Insects The in ect ear con ists of a superficial membrane of thin chitin with an as ociated group of en illae called s olophores Such an apparatus is hown in implified form in Fig 8 The e ears are found in mo t species of katydids c icket gra hopper cicadas waterboatmen mo quitoe and nocturnal and pinner moth They occu in d fferent places in the body on the antennae of mosquitoes on the forelegs of katydids and crick ets on the metath ax of cicadas and waterboat men and on the abdomen of gra hoppers Proba bly the e differently situated organs repre ent eparate evolut onary de elopment through the a sociation of a thinned-out region of the body wall with ensillae that are found ext n i ely in the bodie of in ects and by them elve eem to erve for movement percept on

The in ects mentioned abo e are noted f r their production of tridulatory sound made by rubbing the edge of the wing together or a leg again t a wi g The ound are produ ed by the males and erve for enticing the females in mating

The en iti ity of in ect ears is keene t in the high frequencies Figure 9 hows thre hold curves obtained on a katydid by ob erving the potential produced in the auditory nerve during timulation with ounds A will be een the sensitivity in the pecies is greate t in the region of 1000–60 000 cp It extend to even higher frequencie u ually a high as 120 000 cps and ometimes beyond Other species ha e di tinctly different ensiti ty curve and there is reas n to believe that there i a rela tion to the range of the tridulation ound There is e idence that the e ound a e di crim nated for



Fg 8 E of a g hopp r d g mmat c



Fg 3 Act t h larv f Ph

a d a p ob bly r ed with th ap d tra t u f the body into the t be

Reproduction R p du tive t e i formed f m cell which m lt ply fi st n th th n wall of the blood c ec The phyl m in l des both d e c ou a m ls d hermaphrod tes A the gonad i cre in e te t it di place the a pe it n al ti wh h hr ks p p t n telv Wh n pe th gam tes a hed t the body ty nd find the w y t the ph d to p m thr ugh these s to the t d l at lea t on species (*Ph h ppoc p a*) the o a a et in d io the t nt la r w u t l the larval st ge of de elop m t hed All ph r ds may r p odu e sex ually nd m st a es ti e l f hi t ry i l des th p l g t t h larv Som spec es are kn to p d e asex lly by t n v e fis i S e ANIM L KI G OM [S R M]

B bl g phy L. A B r ad le F A P tts L. E S E th m d J T Sa d *Th I te b at* 2d d 1935 S F Light, R I Sm th, F A P telka D P Abb tt a d F M Wee *Interti d l l t b t s of th C t al C l f a Coa t* d ed 1954 G E MacG n t a d N M cG t e *Nat al H t y f Mari A mal* 1949

Phosphate

A g t n ha ng the fo mula PO Ph s ph t s a d i ed fr m ph ph i acid H PO

The t rm ph ph t s a b o d t rm wh n mp e all d i ed f m a ds ont n g ph ph r th 5+ x dat n state as ind ted i th l r All f th listed ar obta d f m P O and w te

(HPO)	M t ph phor d
H_3PO	T ph ph r t p lyph ph r a id
H P O	Py ph ph ri acid
H PO	h ri cid

The nam ng of th e phosphates i c mplicated b th fa t that the acid co t in se eral hydrogens wh ch an be eplaced stepwi e l y reacti n with a ba e and the fact that ph sphate exi t as poly m r of the impler acid li t d In the ca f the mo t c mmon acid orthophosphoric the alts a e nam d as foll ws pho phate means orth phos phat

NaH PO	Monosodium pho phate Sod um d hyd ogen pho pl ate Primary sodium ph phate
Na HPO	D odium ph sphate Sod um monohydroge ph sphate Seco d ry s dium phosphate
Na_3PO	T i od um pho phate Tertiary di m pho phate Normal s d m pho phate

The alkal metal pho phate and the pr mary alkal ne-earth metal pho phate are li ble in water whereas m t other met l ph phate are p a tic lly insol ble at neutral pH

A lut on of tr sodium phosphate i tr ngl b a d u d as a cl an g comp und a d wat r s fte er Ph sphates are mportant ingredie t in commerci l fertil ze s Natural ph sphate rock can be c n erted i to a u eful fert li er superpl o phat by a react n with sulfu a id

$$C\ (I\ O\ )_3 + 2H_2SO\ + 4H\ O \rightleftharpoons Ca(H\ PO\ )_2 + 2(CaSO\ 2H\ O)$$

An imp rtant u e f polymeri pho ph tes as n ng edient in yntheti d t rgents and as e *que te i g nt*

Th phosphate on gi e llow amm n m pho phomolybdate prec p t t and yellow Ag PO prec pitate wh h serve a alytic l te t

Certain rgan ph ph te ha e b n u ed n e ticid and ner s S e FERTILIZER ORGANOPHOSPHORUS CO POUND PHOSPHORUS [E F W R]

Phosphate metabolism

The a ti e phosph t s ccur i the ft tis u s of the a mal body The pho ph t n mineral d t s es erve a imp rt t t ag depot, con taining 75-85% f ll t e ph sph u the anim l body The f f these stored pho phat s re p e to l wered c nter t in the bl od pla m ot p rt larly effecti Hen the le el of i ganic ph phates in the blo d plasm i el t ly a ly l wer d wh n th d et *ry intake* de qu te f llowed by th appe an e f ympt m f ph pi o s

Tl e tr l le of pho phat n l f p o s d ted by th r ccurrenc i bo- a d d xy b n cle e d h ch e so impo tant p o- i ynthes s nd in th f n ti n f hr m m n th p e f g wth and h red ty Th m j signific e f phosphat n met b l m s th r le n the n rv ti n and t a sfer nergy part cularly the e e gy p oduced th tr box yl c d cycle (K b ycl) and n glycolysis

Fig. 1 *Phoronopsis harmeri* removed from its tube. Length about 20 cm.

tentacles may form either a slightly indented circle or a complex double spiral. The tentacles vary in number from about 50 to over 300, are ciliated, and create a feeding current which carries food particles to the mouth. Feeding and excretory currents have not been studied in detail. Associated with the mouth is a ciliated flap of tissue known as the epistome.

The digestive tract consists of an esophagus, stomach, intestine, and rectum. In some species there is a distinct valve between the esophagus and stomach. The junction of the stomach and intestine occurs at the proximal or aboral extremity of the animal. The food seems to consist chiefly of microscopic phytoplankton. Diatom shells may frequently be found in the digestive tract and in fecal pellets.

There is a blood vascular system in which elliptical, nucleated corpuscles containing hemoglobin circulate. The vascular system consists basically of two longitudinal vessels, known as the afferent and efferent vessels, which are continuous with one another at the proximal end of the body. Distally both vessels connect with a pair of semicircular vessels located at the level of the lophophore, immediately below the tentacles. Within each tentacle is a single blind vessel which branches into two at its base and so connects with both semicircular vessel. In the living animal corpuscles can be seen pulsating up and down in the tentacular vessel. Associated with the longitudinal blood vessels is a blood sinus surrounding the gut and a large number of blind blood caeca which are particularly numerous in, or may be restricted to, the proximal end of the body. Associated with these caeca is the jellylike fat body, or vasoperitoneal tissue. Found among the large, semifluid cells of this tissue are inclusions of various sorts. Some of these probably consist of guanine or some related form of nitrogenous waste. Others may represent the products of hemoglobin breakdown.

The body cavity is subdivided by a series of longitudinal mesenteries extending from the digestive tract to the body wall. In most phoronids there are four such mesenteries occupying oral, anal, right lateral, and left lateral positions, thus dividing the coelomic cavity into four chambers. There is also a horizontal mesentery near the tentacular end of the body, separating a lophophoral coelom from the four larger and more proximal coelomic cavities.

The two nephridia open on either side of the anal papilla. Each nephridium consists of a duct coiled once on itself and usually a pair of funnels, one opening into each of the oral and anal coelomic cavities. The funnels have extensive folded and ciliated margins.

The body wall consists of an outer layer of epithelial cells, many of them secretory and concerned with the building of the tube, and two layers of muscle. The outermost layer of muscle consists of circular fibers and inside this is a series of bundles of longitudinal fibers. An unpolarized nerve net underlies the external epithelium and continues as a more dense concentration in the form of a ring in the horizontal mesentery. Extending proximally from cell bodies in this ring are one or two giant nerve fibers which taper and disappear at the proximal end of the body. The giant nerve fibers are known in all species except one (*Phoronis ovalis*).

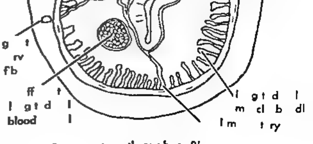
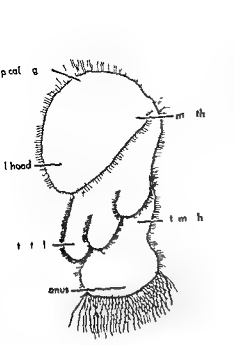


Fig. 2 Cross section through a *Ph*... p...



Fg 3 A t t h l rva f Pho o uv s

a d re p obably c n e ned w th the rap d r trac t n f th body nt the tub

Reproduction Repr duct v ti ue is f rmed f m lls wl h mult ply fi t th thin w lls of the blood a a Th phylum includes b th d› e c) a mal and h rm phrod t As the gon d re s in e t nt t d spl e the a perit n al t u wh h hr nk pr port n tely Wh n ripe th g m tes e shed t the body ity and find the r way t the ephrid t pa s th o gh thes o ga s t the t d I t l a t one pe ies (*Ph o s h pp c p*) the s are etained in the t nta ula ow unt l the larval t ge of de el p- ment s rea hed All ph ds may rep du e e ually nd mo t ca tl life h st y ncl des the p l gi t tr h l rva Some p cie a e kno n t r p odu e exu lly by tr n e e fi o *See* A t IAL KI CDOM [J R M]

B bl phy L A B rr da l F A P tt L E S E tham s d J T S n de s *The I re t b at* 2d ed 1935 S F Light R I Sm th F A T t lka █ P Abbott, d F M Wee r *Int rti d I I t b ate of th C t al C I J n Coast* 2d d 1954 G E M Gin t e d N M cGin ti *Nat l Histo y of M n A mal* 1949

Phosphate

A g t t ▪s t g th f rmula PO Ph s- ph te r de v d from ph ph ac d H_3PO_4. The t m ph gh t t a br d term wh h e mp ▪ ll a t d ed from ac d e nta ning ph ph ru t th 5+ d t on st te nd t d th l t All f th e l ted re obt ed f om P O d w t

(HPO)	M t phosphoric a d
H P O	T iph ph t t polyph pho ic a d
H P O	Py ph phoric acid
H PO	Orth ph sph c a d

The nam ng f the e pho phates ▪ complicated by the fact that the acid contain se ral hydrog n wh ch c n be eplaced tepwi e b reacti n with a ba e and the fa t that pho phate exi t as p ly *m r* of the mpler acids li ted In the ca f the m t common ac d orthoph sphori the s lts are named foll ws pho phate mean rthoph s- pl ate

NaH PO	M no odium ph phate Sod um d hydr gen ph phate Primary sod um ph phate
Na HPO	D dium pho phate Sodium m n hyd ogen phosphat Secondary sodium phosphate
Na_3PO	Tri odium pho phate Terti ry sodi m pho phate Normal odium pl pl ate

Th alkal metal pho phate and the primary alkal e ea th metal pho phates a e lul le in water whereas mo t oth r metal pho phates ar p acti ally in oluble at neutral pH

A oluti o of tr odium ph phate i tro gly ba i and i u ed a a cl aning comp und and wat r ofte e Pho phate are imp rtant ingredients in omm r al fert lizers Natur l ph phate rock can be con erted int a eful fert li er superph s- phate by a re ct n w th sulf ric a d

$$Ca\ (PO\ )\ +2H\ SO\ +4H\ O \rightleftharpoons$$
$$Ca(H\ PO\ )\ +2(CaSO_4\ 2H_2O)$$

An imp ▪ nt u e of p lymer c ph phates as an i gredient ▪ ynth tic dete gents and as e- q t r ng agent

Th ph sphate ion gi es a yell w amm ni m phosph m lybdate prec p tate and y llow Ag PO prec pitate wh ch rve analytical tests

Certain organ c pho ph te h e been used a in ect ides and ▪ rve g ses *See* FERTILIZER ORGANOPHOSPHORUS COMPOUND PHO PHORUS [F E W R]

Phosphate metabolism

The ea t e phosph tes o cu ▪ the soft ti ues of the a imal b dy Th ph sph tes n m eral ed t es erve as a import nt t rage dep t n tain ng 75–85% f all the phosph rus n the animal body The r l a f th e sto ed ph ph te in re sp nse to a lowe ed cont nt n the blo d pl sm is not particul ly ff cti e He ce the l el f i or gani ph phates ▪ the blood pl ma s rel ti ely e ily low r d when th dietary i t ke i nad q ate, f ll wed by the appearanc f ympt m of aph o photo

Th central ole f phosphates in l fe p es i dicated by the o c r n e in b and d xy r b nuclei ac d wh h are mportant n pro- t n ynth nd th function f ch m me i th p o e es f gr wth and h d ty The maj g ifi a ce f ph ph t n m t b l m i th i role n the on rvati n a d t ansfer f en rgy pa tic la ly the e gy produc d n the tri a box yl a id ycl (Kr b cycl) and in gly oly i

They do so by participating in many phosphorylation and transphosphorylation reactions involving sugars and other organic compounds. See CHROMOSOME; KREBS CYCLE; NUCLEIC ACID.

In phosphorylation reactions, compounds are formed which yield relatively large amounts of free energy when their phosphate bonds are cleaved by hydrolysis. Examples of such compounds are creatine phosphate (CP) and adenosine triphosphate (ATP). A central part in the energy storage and transfer in all kinds of living tissue is played by ATP. In both CP and ATP the phosphate bond can be transferred between molecules without liberation of inorganic phosphate. See ADENOSINETRIPHOSPHATE (ATP).

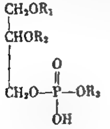
Phosphorus-containing coenzyme systems include the pyridine nucleotide system, concerned with oxidation-reduction reactions; coenzyme A, the functional form of pantothenic acid, concerned among other things with transacetylation in conjunction with ATP and acetic acid; and the diphosphothiamine system, concerned with decarboxylation. See ACETYLCHOLINE; BIOCHEMISTRY; COENZYME. [H H MI]

Bibliography. W. D. McElroy and B. Glass (eds.), *A Symposium on Phosphorus Metabolism*, 1951.

Phosphatide

A complex lipid containing phosphorus and in many cases nitrogen. Phosphatides are also known as phospholipids. The phosphatides are usually divided into groups on the basis of the nonlipid portion of the compound from which they are derived. For example, glycerophosphatides are derived from glycerophosphoric acid; sphingomyelin or phosphosphingosides are derived from sphingosinephosphate; and inositol lipid or inositol phosphatides are derived from inositol monoordiphosphate.

Glycerophosphatides. These are phosphatides which contain a glycerophosphoric acid residue. They are derived from glycerophosphoric acid (I) where $R_1 = R_2 = R_3 = H$. The following com-



(I)

pounds are glycerophosphatides: (1) phosphatidyl ethanolamine or cephalin, where $R_1 = R_2 =$ fatty acid, $R_3 =$ ethanolamine; (2) phosphatidyl choline or lecithin, where $R_1 = R_2 =$ fatty acid, $R_3 =$ choline; (3) phosphatidyl serine, where $R_1 = R_2 =$ fatty acid, $R_3 =$ serine; (4) phosphatidyl inositol, where $R_1 = R_2 =$ fatty acid, $R_3 =$ inositol; (5) lysophosphatidyl ethanolamine, where R_1 or $R_2 =$ fatty acid, R_1 or $R_2 = H$, $R_3 =$ ethanolamine; (6) lysophosphatidyl choline, where R_1 or $R_2 =$ fatty acid, R_1 or $R_2 = H$, $R_3 =$ choline; (7) plasmalogens, where R_1 or $R_2 =$ fatty acid, R_1 or $R_2 = \alpha,\beta$-unsaturated ether, $R_3 =$ ethanolamine or serine; (8) ether lipid, where $R_1 =$ saturated ether, $R_2 =$ fatty acid, $R_3 =$ ethanolamine; (9) phosphatidic acid, where $R_1 = R_2 =$ fatty acid, $R_3 = H$; (10) cardiolipin is a polymer of phosphatidic acid.

Sphingophosphatides. These are phosphatides which contain a sphingosine phosphate residue. There are two known members of this class—sphingomyelin (II) and phytoglycolipid, which is considered in the section on glycolipids.

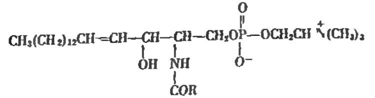
Occurrence and functions. Cephalin, lecithin, phosphatidyl inositol, and the plasmalogens are present in both plant and animal tissues; phosphatidic acids and phytoglycolipid have been found only in plants; sphingomyelin has been found only in animal tissues; and the ether lipid was isolated recently from egg yolk.

Since an individual phosphatide may contain a variety of fatty acid residues, it may be described as pure only with that limitation in mind. Phosphatides can act as protective colloids, wetting and emulsifying agents, and as antioxidants, and are therefore used considerably in the food and petroleum industries. The chief source of commercial phosphatides is soy bean. See LIPID. [H E C; R H G]

Bibliography. H. Wittcoff, *The Phosphatides*, 1951.

Phosphorescence

Sometimes called afterglow, phosphorescence commonly denotes a delayed luminescence, that is, a luminescence that persists after removal of the exciting source. This original definition is rather imprecise because the nature of the detector used will determine whether or not there is observable persistence. In a more rigorous sense, phosphorescence may be defined as delayed luminescence whose persistence time decreases with increasing temperature. In nonphotoconductive systems, phosphorescence arises when processes have placed the luminescent atom (or ion or molecule) in a metastable energy state (from which transitions to the state of lowest energy, or ground state, are forbidden) and energy has been provided to raise the



(II)

at m t an e ergy tat f om wh h l mi e e t t n to a e llowed I ph to ducti e old d ph pho cen gene ally ar s wl n el ct n or h l et f ee by th exc t t n pr nd tr pped t l tr e d l cts a e pelled f om their tr p by dd d e gy (Hole uno cup ed n rgy t t a ene gy b nd th t t n rm lly filled S HOLES t SOLIDS)

Th t mp atu d p de e of pho pho escence lts in a w de va t f fterglow or pe t e t m s At ry low temperatu e whe e the act at n ene gy t t ms f om meta t bl to m tt tat s r to e pel l ctr s f om tr p s n t a labl l ttle o fte gl w t b- erv d At som hi her t mp r t e a l w inte ty l ng l ved ft gl w w ll be b erv d at a t ll h gh t mp tu th aft rglow w ll be br ghter b t f h rte d at F n lly t m h h t m p ature whe e th ate f expul o f t m fr m m ta tabl tate o the at of e t l n of ele t n f m t ps is rv ap d th afte glow an bec m imme u ably h t

The f m e c n d ca law f pho phore c n e n b extr m ly c mpl x d p nding n the num b r a d n rg of the m ta t bl t t l c tr tr p l d Ph sph s ha e b en y the- z d hi h g e a ph ph re cent m s on t bl t th y f bout half a d y at n rmal tempe a t

S LUMI ESCENCE e I o ABSORPTION (ELEC TRO AGNETIC R DIATION) [F C P J H S]

Phosphorus

Ch m l l m nt mb 15 ph ph s P forms th b fa ry l g n mb f mp ı ds the m t mp rt nt l f wh h are th pho ph te Fo e e y f m l l f ph ph t pl y a se t l

r l n all g tr n fer pt e ch a me t bol m ph t nthes rs f n t d m l a t Th l d wh l am g other th g mak p th h r d t r m t l (th h o- m m ph phat mb f co- n m

App x mat ly 3 000 000 000 lb f ph ph e t all ll n the f rm f ph ph t s d a n ll n th Un ted Stat a d ph phat util z t t th in r Abo t 70 f th goe t t fe t l 13 t b ilt d t rg nt 8 n m l feed 2 nt w ter soft ing ppl t

30 nt pharm ceutical and foods 11 int met l prote tion 0 7 int pl sti ize gasoline dd t es and in e ticides and 4 t to m i cella neous applic ti ns

Occurrence and manufacture Of the nearly 200 d ffe e t pho phate m ne al only ne fluorapa t te s mmer ially important This m neral $Ca_5F(PO_4)_3$ is mi d from large ec ndary de- po ts orig nat ng fr m the bones of dead cr a t re depo ited on the bott m of p ehi toric seas and f m bi d dropp ngs in anc ent rookerie In the Un t d St tes the major pho phate deposits are Flo ida T es and the Montana Id ho r g o Othe important depo it are found in Mo- ro c T s a and Ru ia

Con er ion of pho ph te ro k (the nam gi en to the c mmon mp re form f th m eral apa t t) to u ble hemicals ac ompl shed by two m j r r utes wet ac d and l me tal ph phorus In the wet acid pr cess the ph phate rock i treat d with *sulfuri* c d to bta n a ry im re pho ph ri c d plus a *precipitate of* cal um ulfate A large b dy f technology ha been d v l ped t h e e sy rem l of the alc um ulfate and ubseq ient c n entrat on and part al fi atio f the pho phor c a d Unde present day ec nom c ond t o in the United State the c t f m k ng indu t al g ade ph sphates via the w t a id pro e s abo t eq alent t th co t of n ert ng the r t l mental ph sphoru and the b rni g t to gi e highly p pho pho i d whi h on erted into the ph phate In ele *mental ph* phorus manufact re ph phate o k l ca d k a e fed t an elect ic f rnace m wh ch a h gh temp ratur r act on u s to g e the white m d f at n of elem ntal ph phoru P a c le m s l ate lag nd fr m t im purit th ph o ph te r k n ir n pho phid alled f pho pho u P et eatment f the o e em mo t of the flu ne

Alth ugh me lemental pho ph r s i n d a u h n n nd ary b mbs n metall gy nd n the prod t n f rga n de at e and chem cals f m tehe m t el ment l ph pho n rted t pho pho a d by r tr n w th a and wat m l u at g t wer Eleme tal pho- ph r and ph ph i ci d e the st ti mate- r ls fo the nth s f all oth r compound of ph ph r Pho ph r a id i tr ted with da h CO and th e ult ng rthopho ph te omp s t o th n e l ed n larg tar te t mak p o- nd t ip lyph phate ry l g mo t

Phosphorus chemistry Beca e of the t m d u l la g umb of mp nd ba ed r b d *pt* h m t y h s b n di ided t t o ga i wh ch tr t f c bo c mpo f nd i ga h m tr whi h d al with th m d of the 100 dd th l m nt Re nt entific w k n th fi ld of ph ph l m t y nd ate th t f t nt ll th r ma l ma mp und ba d pho ph r a o c bon that th hem try f ph ph m

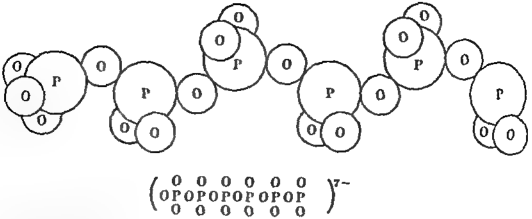


Fig. 1. Long-chain phosphate anion $(P_nO_{3n+1})^{(n+2)-}$. (From R. E. Kirk and D. F. Othmer, eds., Encyclopedia of Chemical Technology, vol. 10, Interscience, 1953.)

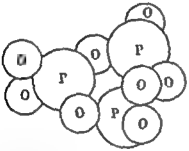


Fig. 2. Ring phosphate anion $(P_3O_9)^{3-}$. (From R. E. Kirk and D. F. Othmer, eds., Encyclopedia of Chemical Technology, vol. 10, Interscience, 1953.)

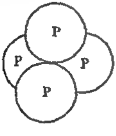


Fig. 3. White phosphorus, P_4. (From R. E. Kirk and D. F. Othmer, eds., Encyclopedia of Chemical Technology, vol. 10, Interscience, 1953.)

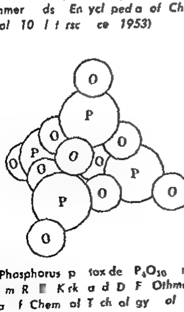


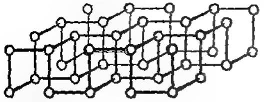
Fig. 4. Phosphorus pentoxide, P_4O_{10}, in the vapor state. (From R. E. Kirk and D. F. Othmer, eds., Encyclopedia of Chemical Technology, vol. 10, Interscience, 1953.)

come a major branch of chemical knowledge. In organic chemistry it has been customary to group the various chemical compounds based on carbon into families which are called homologous series. This can be done in the chemistry of phosphorus compounds, although at the present time many such phosphorus-based homologous series are quite incomplete. The best known of the homologous series of compounds based on phosphorus is the phosphate family. Phosphate salts consist of cations, such as sodium, along with chain anions which may have 1–1 000 000 phosphorus atoms per anion. A structural representation of the end of a long-chain, stretched-out phosphate anion is given in Fig. 1.

As shown in the diagrammatic representation, the phosphates are based on phosphorus atoms tetrahedrally surrounded by oxygen atoms, with the lowest member of the series being the simple PO_4^{3-} anion (the orthophosphate ion). The family of chain phosphates is based on a row of alternating phosphorus and oxygen atoms in which each phosphorus atom remains in the center of a tetrahedron of four oxygen atoms, as shown in the structural diagram. There is also a closely related family of ring phosphates, a member of which, the trimetaphosphate, is shown in Fig. 2.

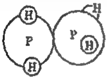
An interesting structural characteristic of many known phosphorus compounds is the formation of cagelike structures. Such cagelike molecules are exemplified by white phosphorus, P_4, and one of the forms of phosphorus pentoxide that with the chemical formula P_4O_{10}. Network structures are also common. An example is found in black phosphorus, in the crystals of which the atoms are bonded together in the form of vast corrugated planes.

In the majority of its compounds, phosphorus is chemically bonded to 4 neighboring atoms. There is also a large number of compounds in which 1 of the 4 neighboring atoms is absent and in which its place is taken by an unshared pair of electrons. Two typical compounds based on this type of phosphorus are shown in Figs. 6 and 7. In addition to the compounds based on quadruply



Fg 5 Bl k ph pho s P (F m R E K k d O F Othm d E cy l ped f Ch m l Te b l gy l 10 l t 1953)

Fg 6 T m thyl ph ph t P(OCH$_3$)$_3$



Fg 7 B ph ph P H (F m R E K k d D F Othm d E y l p d f Ch m l T h l gy ol 10 l t e e 1953)

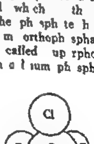
nected ph sph ru a d th s ba d n triply co cted ph phor th a al o f w ompounds n h h ib r ar 5 6 ghb ng at m bonded t th ph ph ru Th e omp ds e ery r a t e nd t d to be un table b s f the use f d o b tals t th t o b del t t u tur E am ples a gi e i F g 8 and 9

Str ct ral gan zat pl y n impo tant role n th h mi try f ph sph ru mp unds Thus f e mpl when vari m xt res f POBr a d POCl re l d a gl s tub and allow d t me t q l b um th t rmed at c mpou d POClB d POCl B fo m d m ious m u t d p d g n th at f the ta t g m t l (F g 10) The POB —POCl eorg n zat l omp d ba ed n a s ngle ph s ph ru t m t wh h bo ded l o yge nd 3 h l g n t m f hlo in d b mi e a e halo l St tu l eo gan zat n also cc s b tw n a memb r f a h m l gou se es f mpo d In th polyph sph ryl hl r d h m l se es eorg n zat takes pl e by ex h f b dg ng yge t m with hl ine at m t a the POBr —POCl s t m th e ha ge bet ee hlo ne a d b m t m Th a t l u t n a polyph pho yl hl d mpo t on a the m ph ph ru c m pou d POCl th d g p Cl(O)PO — th m ddl gr p —O (Cl)P(O)O$_{4}$— nd the l n hi g g oup OP(O —) n whi h th br dg g yg t m a h w a O$_{4}$ s e they shared between ne ghb ing pho phorus atoms A typical structure in a polyphosphoryl chloride is sh wn in Fig 11

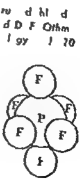
When va ious ratio of chl r ne to o ygen re empl yed the di tributi n of the tructural units changes as hown in Fig 10 whe e *A* stands for the m nophospho phorus comp und POCl$_3$ *B* for the nds C for the m ddles *D* f r th an he and *D'* f r th mpl tely b a ched comp und pho phorus p ntox de The end middles nd branches do n t exist by th msel es but must be combi ed together to form chemi al compo nd The line labeled *x* in th figu e repres nts the l mit b nd wh ch th re is a sufficiently large prop rti n of branch ng po nts that infinite wall to-wall m lecu la tructu e bec me stati t cally probable The pr s n f such w ll to-w ll molecul tructu es in th mi tu e of va ious s zed and haped p ly pho phoryl hlo ide m lecule lead to high is co t a d n t ceable elast c behav or

In sp te of th fa t that homologous e i and ompo nds ba d on a number f phosphorus atoms are mphasized n thi art cle the extens chemical l t atu e before 1950 deal ng with phosph rus chem try was re t icted almo t entirely to comp und thought to be ba ed on a s ngle phosphoru atom (monoph sph rus compounds)

Principal compounds and uses E ntially all of th pho phoru u ed in c mm rce is in the f rm of pho phates The majority f pho phatic fert l rs cons st of highly mpure monocal i m or d calc m rth pho ph te Ca(H PO$_4$) and C HPO These ph sphates a e alts of o thoph sph ri ac d wh ch th mon phosph ru mp und in the ph sph te h m log series Impur d al i m orthoph sphate fo fert l z u e u ally called up rpho ph te whereas the impure mon c l ium ph sphate u ed in th



Fg 8 Ph sph ru d hl d t fl d PCl F (F m R E K k d D F Othm d E y l p d f Chem c l T h l gy l 10 l t 1953)



Fg 9 H fl ph ph te PF

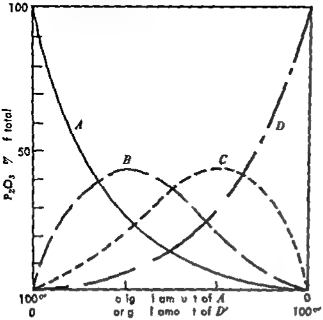


Fig 10 Reorganization equilibria where A is $POCl_3$, B is $POCl_2Br$, C is $POClBr_2$ and D and D' are $POBr_3$

application is called triple superphosphate *See* FERTILIZER

Two properties of the family of chain phosphates have led to numerous industrial applications for these compounds These properties are deflocculation of colloidal particles and formation of soluble complexes with cations The chain phosphates are strongly adsorbed on the surfaces of inorganic solids and hence give these surfaces high negative charges When finely divided particles bear such high charges they repel each other and are deflocculated peptized or dispersed An interesting example of this phenomenon is found when a plastic clay water mass is treated with a chain phosphate By addition of perhaps a few tenths of 1% of sodium tripolyphosphate to a plastic mass of clay suitably rigid for sculpturing the clay particles are deflocculated so that the mass liquefies to a consistency similar to that of tomato soup

The formation of soluble complexes with cations has often been described under the term sequestration because a complexed ion is sequestered or hidden away in the solution so that it no longer exhibits its normal chemical reactions The calcium and magnesium of hard water are sequestered by the addition of small (stoichiometric) amounts of chain phosphates so that the water is effectively softened The complexed calcium will then no longer form precipitates with the carbonate or sulfate in the water to give pipe scale or with soap anions to give for example a ring around the bathtub

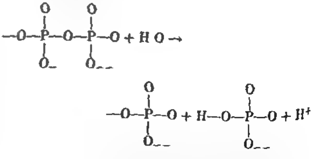
The third member of the family of sodium phosphates sodium tripolyphosphate is the major compound used in building synthetic detergents to achieve improved cleaning primarily by dispersing inorganic soil and softening the water The average household detergent produced in the United States for washing clothes consists of 50% by weight of sodium tripolyphosphate $Na_5P_3O_{10}$ This compound is used extensively in water softening as are other members of the homologous series of chain phosphates *See* DETERGENTS SURFACE ACTIVE AGENTS WATER SOFTENING

An interesting water softening application is found in threshold treatment in which tiny traces of a chain phosphate (much less than would be used in sequestering) are used to prevent the formation of pipe scale from hard water This application is related to the dispersing action of the phosphates because traces of phosphate adsorb on the growing surface of the pipe scale as it begins to form and thus inhibits its further growth

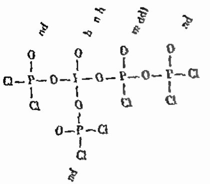
A major pharmaceutical use of phosphates is in toothpaste in which dicalcium phosphate is the most popular polishing agent Monocalcium phosphate and sodium acid pyrophosphate $Na_2H_2P_2O_7$ (the pyrophosphate is the second member of the phosphate family) are employed as leavening agents in cake mixes refrigerated biscuits self rising flour and baking powder

Special mixtures based on orthophosphoric acid H_3PO_4 are used to phosphatize metal surfaces In this treatment the surfaces become covered with a thin adhering layer of insoluble orthophosphate salts which protect the metal from corrosion and offer an especially adherent base for painting Automobile bodies for example are now generally phosphatized before they are painted to prevent rusting in use Orthophosphate esters find wide use as plasticizers having flame-proofing properties and as gasoline and oil additive

The phosphorus compound of major biological importance is adenosine triphosphate which is an ester of the salt sodium tripolyphosphate widely employed in detergents and water softening compounds Practically every reaction in metabolism and photosynthesis involves the hydrolysis of this tripolyphosphate to its pyrophosphate derivative called adenosine diphosphate The hydrolysis of chain phosphates occurs through splitting of a P—O—P linkage as indicated in the following chemical equation



In neutral solution at room temperature the rate for this process is extremely slow However enzymes increase the rate many thousandfold The equilibrium between adenosine triphosphate water adenosine diphosphate and the orthophosphate ion is strongly shifted toward the hydrolysis products



Fg 11 l p t polyph ph ryl hl d P O Cl

ad no diph phat and the orth ph phate ion Becau l thes f ct orga c re ctions n b ol l sv t m re n turally co tr lled o that l fe can exi t S ■ ADENOSINETRIPHO PHATE (ATP)

[J V W]

B ll aphy J R V n Wa er *Phospho us a d Its C mpou ds* 1 1 1958

Phot

Th t of illum nation wh n the sq are centi m t r t k the n t of ar It i eq al to the d n ty f e l me per qu r ntim t r d i defi ed i im la m nn r a the f ot an dle a d the l x S e FOOT CANDLE ILLUMINA TION LUX

[R C P]

Photochemistry

Th b a h of chem try de l ng w th the inter el t h p betw e light a d h m c l acti ns Ph t chemi t y l des the tudy f chem l e a t n p odi ■ t prod c d by ble and It a l t l ght f w el ngth b twe n tho e f i f ared l ght and x ay Th g n f the pec t um lud u l ght o ola n rgy as t re hes th th ru t nam ly the a nf ar d i ble d a lt l t p rt f u l ght b tw en 12 000 d 3000 g t m (A) d l ght t ex t at a ll t ty t r pa e m ly down t l t 1000 A Th ma m m nt n ty of un l ght the red p rt f th pect um b twe 6000 a d l 000 A Rad t hem t y pe t in to t d es f th hem c l ea ti n ■ odu d by y ay d p rti les h a elect ns of bo t th am h gh r ergy q al t Comm ph t h m l r t ar th n t l ph t nth t proces a d ph t graphy Cl m i al t p od n l ght e ally de t fied t rni g r mb t Th h m l a t n th fi fl a d th h m l r t re ti n h t p od e ld l ght.

I th t l pl t th t e p oc ss th r ac t n b ght abo t by light ab bed by chlo ph ll Th ll r a t n ho ld b w tt

$$CO_2 + 2\ H_2O + l\ ght = (CH_2O) + O_2 + H_2O$$

i order to ind cate that all the oxygen gas c mes fr m the water and none fr m the carb n d oxide Th s h s bee proved by employing the xygen i o top of ma s 18 t follow the path of oxygen in the proce The path of carbon in the pr e s has been followed by emplo g th radi act ve carbon i tope of ma 14 Very little is known h we er about the way in whi h the l ght ab orbed by the chl ro phyll b ngs about the react on

The un t of light energy m st u eful in photo chemistry is the ph ton $= hc/\lambda$ where h is Pl nck s n t nt ($6.5 \times 10^{-}$ rg ec) c i the loc ty of l ght (3×10 c n/ ec) and λ i the wavelength of the light in cm ($1A = 10^{-}$ cm)

Anothe pl tochemical nit of light ne gy is th e n t n wh ch i the energy of 6×10 or 1 mole N f light quant Thu l ein t n of red light is $h = Nhc/\lambda = (6 \times 10 \times 6.5 \times 10 \times 3 \times 10)/(6700\ A \times 10) = 17.5 \times 10$ erg r $(17.5 \times 10)/(4.186 \times 10) = 42\,000$ cal Thi am unt f ene gy i greater than th acti ation e e gy required t initi t many the mal e cti n

Quantum yield The effic e y of a photo hem cal ■ ct n is u u lly expre ed in terms of th quantum yield which is q al to the numb r of m l of the tated reacta t d ppearing or to th umber of mole f the stated pr du t produ d per in tein f l ght f the tated w le gth b bed Th gr s q a tum yield is c l ulated from the l ght ab o bed by th ent re ph t n iti sy te N t qua tum y eld is b d on the light ab s rbed by the t t d comp n nt or p cı s of the sy tem I h t h n cal r action are mo t e ly nde t d n te m f net q a t m y lds

Photochemical reactions Ph to h m try may l o be defi d as the h m try of ene gy ri h pl t n ex ted t tes When p du d by th ab o pt on of is bl or ultra let l ght these a l t o cally xcited state e ult ng f om the tra fe of a le t on t a l h r nergy lev l Th t m req i ed f th s tr fer i o h rt that d i g th s t me the p sit n of th uclei of th at ms i d main unchan ed Thi known a th F nck C nd n principle

F ll w ng thi pr mary act n of gr at many d ffer nt k nd f p ces m y take pl e

1 P od t n f n rgy r ch inglet nd tr plet t t f llowed by fl re enc ph sphor nc nd deg ad t o l th l o bed ene gy t h t

2 Tr nsfe f the l ct n ne gy o tr n fe f elect on ph ton r hyd g n at m t r f m th r pec

3 Br ak g apart of cited re ch Cl i Cl atom O nt O nd O

4 P od t o f a w de v iety of ch m l r ac t Am g thes a t on a the le tr n tr n f ti n i wh h w t r decompo ed i t h dr gen a d xyg by l ght ab o bed by c r um o w t r to tra a d t a s t c m izat n a in the ca e f th ndig hift ■ of th po t n of do bl bo ds a wh n ergo t l n t ted t itam n D d c t n f the excited

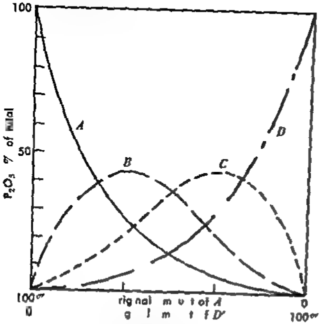


Fig. 10. Reorganization equilibria where A is $POCl_3$, B is $POCl_2Br$, C is $POClBr_2$, and D is $POBr_3$.

application is called triple superphosphate. See FERTILIZER.

Two properties of the family of chain phosphates have led to numerous industrial applications for these compounds. These properties are deflocculation of colloidal particles and formation of soluble complexes with cations. The chain phosphates are strongly adsorbed on the surfaces of inorganic solids and hence give these surfaces high negative charges. When finely divided particles bear such high charges they repel each other and are deflocculated, peptized, or dispersed. An interesting example of this phenomenon is found when a plastic clay-water mass is treated with a chain phosphate. By addition of perhaps a few tenths of 1% of sodium tripolyphosphate to a plastic mass of clay suitably rigid for sculpturing, the clay particles are deflocculated so that the mass liquefies to a consistency similar to that of tomato soup.

The formation of soluble complexes with cations has often been described under the term sequestration because a complexed ion is sequestered or hidden away in the solution so that it no longer exhibits its normal chemical reactions. The calcium and magnesium of hard water are sequestered by the addition of small (stoichiometric) amounts of chain phosphates so that the water is effectively softened. The complexed calcium will then no longer form precipitates with the carbonate or sulfate in the water to give pipe scale or with soap anions to give, for example, a ring around the bathtub.

The third member of the family of sodium phosphates, sodium tripolyphosphate, is the major compound used in building synthetic detergents to achieve improved cleaning, primarily by dispersing inorganic soil and softening the water. The average household detergent produced in the United States for washing clothes consists of 50% by weight of sodium tripolyphosphate, $Na_5P_3O_{10}$. This compound is used extensively in water softening, as are other members of the homologous series of chain phosphates. See DETERGENT; SURFACE-ACTIVE AGENT; WATER SOFTENING.

An interesting water-softening application is found in threshold treatment, in which tiny traces of a chain phosphate (much less than would be used in sequestering) are used to prevent the formation of pipe scale from hard waters. This application is related to the dispersing action of the phosphates because traces of phosphate adsorb on the growing surface of the pipe scale as it begins to form and this inhibits its further growth.

A major pharmaceutical use of phosphates is in toothpaste, in which dicalcium phosphate is the most popular polishing agent. Monocalcium phosphate and sodium acid pyrophosphate, $Na_2H_2P_2O_7$ (the pyrophosphate is the second member of the phosphate family), are employed as leavening agents in cake mixes, refrigerated biscuits, self-rising flour, and baking powder.

Special mixtures based on orthophosphoric acid, H_3PO_4, are used to phosphatize metal surfaces. In this treatment the surfaces become covered with a thin adhering layer of insoluble orthophosphate salts which protect the metal from corrosion and offer an especially adherent base for painting. Automobile bodies, for example, are now generally phosphatized before they are painted to prevent rusting in use. Orthophosphate esters find wide use as plasticizers having flame-proofing properties and as gasoline and oil additives.

The phosphorus compound of major biological importance is adenosine triphosphate, which is an ester of the salt sodium tripolyphosphate widely employed in detergent and water-softening compounds. Practically every reaction in metabolism and photosynthesis involves the hydrolysis of this tripolyphosphate to its pyrophosphate derivative called adenosine diphosphate. The hydrolysis of chain phosphates occurs through splitting of a P—O—P linkage as indicated in the following chemical equation

$$-\mathrm{O}-\underset{\substack{|\\ \mathrm{O}^-}}{\overset{\substack{\mathrm{O}\\ |}}{\mathrm{P}}}-\mathrm{O}-\underset{\substack{|\\ \mathrm{O}^{--}}}{\overset{\substack{\mathrm{O}\\ |}}{\mathrm{P}}}-\mathrm{O} + \mathrm{H_2O} \rightarrow$$

$$-\mathrm{O}-\underset{\substack{|\\ \mathrm{O}^{--}}}{\overset{\substack{\mathrm{O}\\ |}}{\mathrm{P}}}-\mathrm{O} + \mathrm{H}-\mathrm{O}-\underset{\substack{|\\ \mathrm{O}^{--}}}{\overset{\substack{\mathrm{O}\\ |}}{\mathrm{P}}}-\mathrm{O} + \mathrm{H}^+$$

In neutral solution at room temperature the rate for this process is extremely slow. However, enzymes increase the rate many thousandfold. The equilibrium between adenosine triphosphate, water, adenosine diphosphate, and the orthophosphate ion is strongly shifted toward the hydrolysis products.

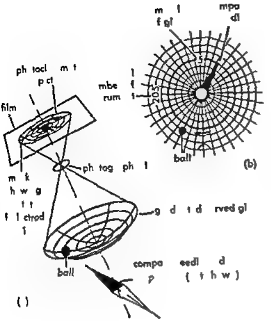
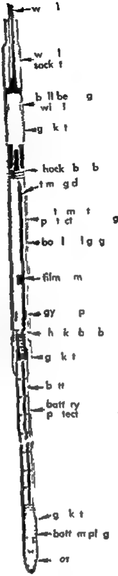


Fig 1 ( ) P p l f t f th S hl mb g Ph tocl om te (b) Typ f ord bt d w th th S hl mbe g Ph t l m t (S hl mb g W ll S rv y g C p)

Schl mb Ph t cl om t and th S w ll Cl n g aph B th t m t e d t s of dev t n m ment e tr p t nd om f th well F m th s r f d ta it p able t pl t q it ac at ly th co e f the well

I the Schl mb Ph tocl m ter th d via t o f om tl e rt cal t d at d by sm ll metal ball wh h ll t n p r t gl s b wl grad t d n l d gree Th d t n f the de t azim th d ted by magn t mp s W th th t me t pe d d by ele t t al abl the p t f th e mpa d t el b ll ph t g ph d n 35 mm film b p a t f lect l t l t th rf wh h t m l ght th n t me t d ap the mer h tte Aft th p t t k the film m d t n w po t P t b tak t t f l t p m t Cor l t f th p tu es w th th d pth t wh h th y e t k



Fg 3 V rt f ct th gh S rw ll cl g ph (Sp y S W ll S y g C)

(kn wn by th l gth f the su pe d g cable) y ld a m asure f the m g t d and d r ct f d t o of the hole as a fun t n f d pth

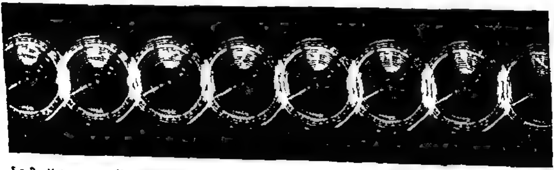


Fig 2 M tio -pict f lm o d m d by th S rw ll l g ph (Sp y S W ll S rv y g C)

species into atoms ions molecules and radicals changes in the acidic or basic strength of the light absorbing species polymerization reactions germicidal action sunburn and tanning

In its broadest sense photochemistry may properly be said to deal with the study of any of these processes In a narrower sense however photochemistry deals only with the chemical reactions brought about by absorbed light This includes studies of the kinetics and mechanisms of reactions such as that between H and Cl to produce HCl In this case only Cl_2 absorbs visible and near ultraviolet light and the reaction proceeds mainly as follows

$$Cl_2 + \text{light} = 2Cl \quad (1)$$
$$Cl + H_2 = HCl + H \quad (2)$$
$$H + Cl_2 = HCl + Cl \quad (3)$$

The net quantum yield for this chain reaction is over 1 000 000 under favorable conditions

Light absorption The fraction of the light absorbed by a stated component or species in a system requires a knowledge of the relative concentrations and light absorbing powers of all the species in the system which absorb a significant amount of light Concentrations for this purpose are stated in terms of the number of light absorbing species per unit volume for example in moles per liter Light absorbing powers are expressed in terms of a constant which is characteristic of the stated species in the stated environment at the stated wavelength such as the molar absorptivity $\varepsilon_l = A_l/c$ where $A_l = \log_{10} I_0/I$ c is the concentration of the stated species in the stated environment and l is the length of the light path over which the light intensity of the stated wavelength decreases from an initial intensity I_0 to I because light is absorbed by the stated species *See* SPECTROPHOTOMETRIC ANALYSIS

Light sources The interpretation of a photochemical reaction is greatly simplified when concentrations are uniform throughout the reacting mixture This requires that the light fill the whole system and be weakly absorbed or that there be adequate mixing especially in the parts of the system absorbing most of the light

Light intensities light absorbing powers and quantum yields sometimes change rapidly as a function of wavelength so that quantitative photochemical studies are best carried out with monochromatic light or with light consisting of a suitably small range of wavelengths

Monochromatic light is conveniently obtained by employing atomic light sources which emit the desired wavelength as part of a discontinuous spectrum The desired light must be sufficiently different in wavelength from the other emitted rays so that it can be isolated easily at a relatively high intensity A common light source is the mercury arc lamp

Monochromatic light intensities obtained from most light sources are usually low Therefore the success of a photochemical study often depends upon the proper design of an apparatus for isolating and bringing to bear upon a sufficiently small volume of the photosensitive system most of the light of the desired wavelength emitted from the light source Monochromatic light is isolated successfully for photochemical studies by means of filters or monochromators and occasionally by means of focal isolation

Whenever possible advantage is taken of the fact that the photosensitive system may absorb a suitably small range of wavelengths of the light incident upon it although the latter may consist of a very wide range of wavelengths Under these conditions however the evaluation of the light absorbed by the system is especially difficult

Measurement of the light absorbed by a system has been accomplished by means of chemical actinometers bolometers thermopiles and phototubes with proper auxiliary equipment The uranyl oxalate and ferric oxalate actinometers are convenient and reliable

Energy relationships It is sometimes convenient to think of a photochemical reaction in a liquid system as being initiated in a photochemical cluster not unlike the critical complex of thermal reaction There is however one important difference namely that the products of a photochemical reaction may contain as chemical energy a significant fraction of the energy of the absorbed light, even when the reaction is essentially complete whereas thermal reactions do not take place to any significant extent if the free energy of the products is greater than the free energy of the reactant The latter is also true of photochemical reactions when one includes the energy of the absorbed light as part of the free energy of the reactants

The elucidation of photochemical reactions is often easier in terms of changes in net quantum yields than of changes in rate constants Also it is often possible to identify the part of the light absorbing species responsible for the light absorption and thereby obtain information about intramolecular as well as intermolecular energy transfer processes and accompanying thermal reaction *See* FREE RADICAL LIGHT LUMINESCENCE PHOTOGRAPHY PHOTOSYNTHESIS RADIATION CHEMISTRY SPECTROSCOPY [L J H]

Bibliography F Basolo and R G Pearson *Mechanisms of Inorganic Reactions* 1958 E J Bowen *The Chemical Aspects of Light* 2d ed 1946 L J Heidt Converting solar to chemical energy *Proceedings of the World Symposium on Applied Solar Energy* 1956 C Reid *Excited States in Chemistry and Biology* 1957 A Weissberger (ed) *Technique of Organic Chemistry* vol 2 2d ed 1956

Photoclinometer

A term applied to directional surveying instruments which record photographically the direction and magnitude of well deviations from the vertical Two instruments of this type are in wide use the

the curr nt fl ws fo too l ng (say 4 min) a much mo e ompl x ph nom n n called se ndary ph t d tiv ty may e ult

E it n ind ed ph t ondu ti ity occ m al kali h l d th t onta n lor ce ter if the n cid nt r d t n lies n the f t i tr nsic (fun d mental) pt al ab rpti n peak f the rystal n ll (F r p t i m i d de thi peak li s at a phot e g of 5 6 e in the fa ult a ol t) Th ffect i l k e t d ed ph t emi on cept th t th ted ele tr ns rem n i the ry tal It occur i two tage The b rbed ph t pro d e t wh h re l ctr cally ne tral en t t es The tl n tra f r gi en gy t e l e nt r to ej ct elect ns The eaft r th p oc i m l r to primary ph toc r d ct tv Ex t n i d ed phot ndu t on e r also in c y tal uch b rium x d *See* EXCITON

Int i c ph to o ducti ity i lkal hal d takes pla he l ght i al b d ir th de l p r r tal latt e with the r ulta t pr du tion of m b le electr a d p t v holes (s e HOLES t SOLIDS) In th al n e of d fe t s h s e lor e t ph t ondu ti n d e t ur t en rgi s orr po d ng t th fi t pt c l ab rpt on peak (a alk l h l l The c ncept of e c t n s nea tr f p rt l de el ped t d d be au e f thi p m tal fa t At sli htly h her ph t n e xpect ntr c ph to ndu t ity t t It nalog t the t i phot emi n h h l p t s m d d t about Ph to nd t h ld t in t l htly l w ph t e g tha ph t mi n It d ffi ilt t m a at ly

Silver halides Ph t h g ne gi s just h gh gh t pr du opt cal ab o pt n in a p l e l l l al p od ele t ns a d h le Intrin ph t ndu t ty e It Th th s l h l d ia d n o t a t t p r alkal hal de in h h pt l ab pt n th fi st fundame t l l pt n h nd d e not p d i t in i ph to nd t ty Th ti n f p t e h le n d e hl d i p l il h l d i appa ntly not r p i l l Th l t o th th h d e m m h a l m p im t lly f ibl lect fi ld Th mot n f l t s fi n l m t l b lectr tr p (Th es IN SOLIDS) The l t migrat n th n esembles th t f e t i ph toc d t ty i ed by ol ent n al k l h l des At ph t n n rg t 6 the x i d lect g i that m f them ap th gh th fac d t ph to m n li

Ph t c d t n th e que t on m t tl l h l des pl y imp i t r l t th th t g pl p oce S PHOT GR PHY

Germanium I i e tatt n f ph toc d t i g rma i m typ c l l m t l m n l i oc u f ph ton n the fu da m t l l t i pt l l rpt l nd Th s l l h edge at abo t 0 ev i th i f a d s d t t d t n ly th gh h gh ph t n en gies in th i ibl a d ultra iolet reg ons Elec tr des a e connect d t the germanium crystal to furn h an elect ic field El ctrons r po iti e hole can pa s f om the conn ctions into the cry tal and an el t e cu re t fl ws th ough the specimen n the dark When th ry tal i Illuminated addi tional l ct on and h l s ar reated in equal num b rs In gene al both the excess current carr ers mo e in th ele tric field a d c ntrib te to the pho t c nd i t ity An importa t con iderati n is that the nple m t contain them i equal n mbers (this is call d th cha ge neut ality nd tion) oth erwi e pr h b t e el ct i fields w uld b ild up Thus if an lectr n lea e th ample th ough ne lectrode an the electron enters at the oth r e d Alt rnati ely an lectr n nd *hole may ann h late* n an th r i r comb n ti n pr c ss D rect re c mb nat n is p l le but not ve y pr bable Al m st ll of the recombi ati n t ke plac at def cts o impu it es alled *recomb nati n ce t r* me f wh h m y be at th ampl urface If the il lumi ati s t rned ff the con ntrat n f exce s el trons and l l s (and the ef e the phot c n du t ve urrent) d appear s a functio of time in n e p nent al w y It de r a e by a fact of $I = 718$ in a ateev l e wpi h i all d the l fet me fo el t on hol pa r Th s time i deter m ned by the n mb r and type of e omb nat n e te s in the parti ula sample. F r ry pure germ nium ryst l at rd ry temp r tu es th pai lifet me i l m c or h h r

To c l ul t the magn tude of the photoc nduc t e c nt t n enient to ns de a cube of ge m ni m l em a de with el ct odes on tw ppo te f e If N phot /s ar ab rbed uni formly in th s olume the umb of xc f elect on nd h l a he a steady ncent at on Nt (f each c rr er type) The num ber f elec tro P flow ng p e o d thr gh the battery the exte nal c rc t i

$$P = VNt(\mu + \mu_h)$$

wh re V i th batte y olta and μ and μ_h are th m b l t e of th el t s and h l pe ti ely The t $G = P/N$ d te m n the s ti ty nd c ll d the ph t o d t ga n fact r Now th tr t t me T r q ed fo ele t n t tra er e the g m n m mple $1/V\mu$ that for hole i $T_h = 1/V\mu_h$ Th the g m y be ex pre ed s

$$G = t\left(\frac{1}{T} + \frac{1}{T}\right)$$

If the germ n um c be i t rd nary temperatu w th $t = 10^{-}$ ec and $V = 1$ It G al t 5

Ph t ond t of thi s me ge l ki d o u n il c n nd i c t n omp nds h nd m ant mon d

H gh ga n ph t ond cti n c wh n l t o l l t ap a e p e nt c y tal of g m n um F x mpl Kel t m d l h

The Surwell Clinograph also operates electrically but is powered by batteries contained in the instrument. The deviation from the vertical is indicated by a box level gage and the direction in azimuth by a gyroscopic compass, permitting its use inside steel pipe. This operation is not possible when a magnetic compass is used unless the pipe is made of special nonmagnetic steel. Since the instrument also contains a watch and a dial thermometer, a simultaneous record of amount and direction of deviation, temperature, and time can be made on 16 mm film. Readings are taken both descending and ascending at regular intervals which are preset on the instrument before it is lowered on a wire line into the well, thus providing a check on accuracy. Level gages having maximum inclinations of 20, 40, and 55° respectively are provided to be used according to the magnitude of deviation. [H.C.BO.]

Bibliography: L. C. Uren, *Petroleum Production Engineering: Oil Field Development*, 4th ed., 1956.

Photoconductive cell

A device for detecting or measuring electromagnetic radiation by variation of the conductivity of a substance (called a photoconductor) upon absorption of the radiation by this substance.

To detect or measure the radiation, the cell is connected in series with an electrical source and a galvanometer. The current through the cell is a function of the intensity of the radiation falling on the cell. The galvanometer measures the current.

Photoconductors can be classified into the elemental type, such as selenium, iodine, boron, diamond, germanium, and silicon, and the compound type, such as the sulfide, selenide, and tellurides of lead, thallium, and cadmium. Each of these materials must be doped with the proper amount of a selected impurity.

The photoconductor is usually prepared in the form of a thin film by evaporation of the material under vacuum, by chemical precipitation, or by sintering of the powdered material.

Cadmium sulfide cells are extensively used in the visible spectrum for industrial applications because of their high sensitivity. However, they have a certain inertia, and their response depends upon previous exposure to light (hysteresis). They also generate a relatively high current when not illuminated (dark current).

The antimony sulfide cells are less sensitive than the cadmium sulfide cells, but their response time is much shorter and they do not display any hysteresis.

Lead sulfide and lead selenide cells are especially sensitive to infrared radiation and their sensitivity toward the higher wavelength increases at low temperature. For measurement in the far infrared, certain cells are cooled with liquid hydrogen (−250°C).

Photoconductive cells are characterized by their sensitivity in infrared (1–5 microns) and their short response time. They are used for high-speed recording, high-resolution spectroscopy, television, electrophotography, and as infrared detectors. For more detailed information see INFRARED DETECTOR; *see also* PHOTOCONDUCTIVITY; PHOTOELECTRIC DEVICES. [J.J.RO.]

Bibliography: R. G. Breckenbridge (ed.), *Photoconductivity Conference*, 1956.

Photoconductivity

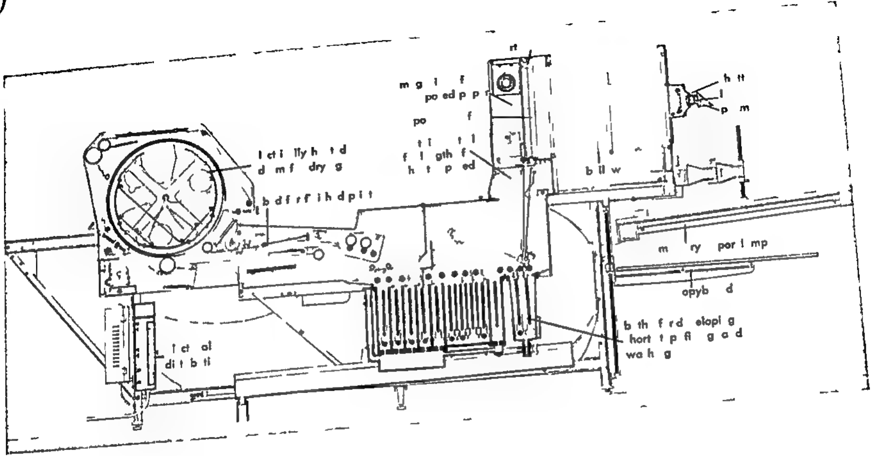
The increase in electrical conductivity displayed by many nonmetallic solids when they absorb electromagnetic radiation. The radiation may lie in any part of the spectrum from the infrared to the x-ray and γ-ray region. Photoconduction may proceed by several different mechanisms, depending on the type, the composition, and the crystal perfection of the solid involved. Photoconduction finds considerable practical application in television cameras, infrared detectors, light meters, and indirectly in the photographic process.

Alkali halides. Photoconductivity due to color centers in alkali halides (frequently called primary photoconduction) occurs in crystals such as common rock salt (sodium chloride) if they have been heated in sodium or other alkali metal vapor. This treatment gives rise to imperfections called color centers which color the crystal. These centers are lattice sites at which electrons take the place of missing negative ions; the color centers absorb visible light (*see* COLOR CENTERS). As a result, the electrons are set free and they are set in motion when an electric field is applied to the crystal. This motion induces electric charges on the electrodes that supply the field. Current flows in the external circuit even though no charges pass from the electrodes into the crystal.

After being set free by the light, the electrons usually move only a short distance before they are stopped. This happens mainly at other color centers. The distance over which the electrons move is called the range, and it increases as the applied field is made stronger. The photoconduction is approximately proportional to the field strength as long as the electron range (in a typical case 10 cm) is shorter than the sample length. When this is no longer true, the freed electrons move to the end of the sample. At this point, the photoconduction is constant with increasing applied field.

This photoconduction is excited most easily by photon energies lying in the optical absorption peak of the color center. For potassium iodide, a typical alkali halide, this peak is centered near 1.6 ev in the red region of the spectrum. Primary photoconductivity can also occur, however, at higher photon energies. Above 2.5 ev in the blue and ultraviolet spectral region, the electrons ejected from the color centers have enough energy to escape through the crystal surface. They then constitute a photoemission. *See* PHOTOEMISSION.

Primary photoconductivity usually occurs for only a relatively short time in an alkali halide. If



Fg 1 D g m f t p i m t c ph t pi (Ph t t t C p)

added as impurities behave as hole traps in germanium near the temperature of liquid nitrogen If an appropriate amount of arsenic is also present each Ni atom becomes a doubly negative ion Ni Because of its strong negative electric charge it repels electrons and attracts positive holes Thus when illumination ets both holes and electrons free in the sample the Ni ions quickly capture holes Accordingly the doubly negative Ni becomes singly negative Ni It is still negative and it still repels electrons Thus recombination of electrons with the captured holes is drastically reduced and the hole is said to be trapped It is immobile and does not contribute to photoconduction However for each trapped hole a mobile electron is held in the crystal to preserve the condition of charge neutrality Recombination occurs after a comparatively long time called the free electron lifetime t It determines the speed with which the photoconductor responds to changes in illumination The photoconductive gain is in this case t T where T as before is the electron transit time At the low temperature considered here T is about 10 sec if the sample is a cube of unit volume and if 1 volt is applied by the battery Thus the gain becomes 10 and for every photon absorbed in the sample a great many electrons flow through the external circuit The gain increases as the applied voltage increases but complications prevent it from increasing indefinitely

High gain photoconductivity of the same general character occurs in many other materials such as cadmium sulfide cadmium selenide and lead sulfide It was recognized in many of these before being studied in germanium It is not understood quite as precisely as in germanium because the traps are not yet as well identified and because it is more difficult to control the composition and perfection of the crystals On the other hand high gain can occur in cadmium sulfide for instance at ordinary temperatures and is important for application in photoconductive device For the germanium photoconductors a high sensitivity or gain corresponds to a proportionately long response time In more complex photoconductors the response may be sluggish even when the gain is low This usually means that both electrons and holes are being trapped frequently in complex fashion

In germanium and other semiconductor extrinsic excitation of photoconductivity occurs when radiation ejects electrons or holes directly from impurities into the conduction band or the valence band Photon energies may be much less than those in the intrinsic optical absorption range and the photoconductor may respond much farther into the infrared

In certain cases the condition of charge neutrality may not be satisfied in semiconductors The photoconductivity then behaves in a more complicated manner than outlined here *See* ABSORPTION (ELECTROMAGNETIC RADIATION) LUMINESCENCE [L.A.]

Bibliography H G Breckenridge B R Russell and E E Hahn (eds) *Photoconductivity Conference* 1956 C Kittel *Introduction to Solid State Physics* 2d ed 1956 F Seitz and D Turnbull (eds) *Solid State Physics* vol 8 1959

Photocopying processes

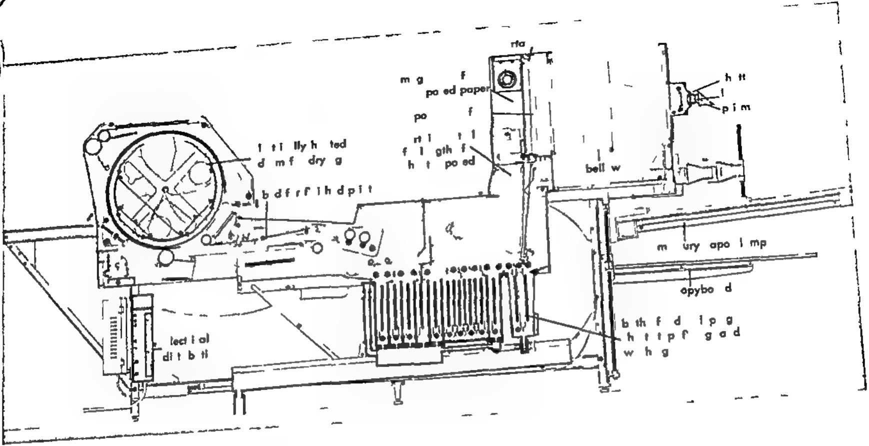
Those means by which a copy is created on a sensitive surface (generally paper film or metal plate) by the action of light The term is generally applied only to documentary reproduction It is distinct from the photographing of gross objects (portraiture for example) from cinematography and from other highly specialized applications of photography although these applications frequently overlap or are combined with photocopying of documents The document to be photocopied must already have been prepared by other applications of photography by manuscript or by typewriter A document in this case is classed as either a line drawing or continuous tone illustration or a combination Some photocopying processes do not handle tone satisfactorily

Photocopying offers practical printing method for the production of a single copy or a limited number of copies or for the production of a stencil or master from which to run off larger number by use of diazo paper or offset lithography It falls into several chemically distinct processes distinguished by the chemistry of the photographic material and its development and fixation Several sensitive materials are used—silver halide salts diazonium salts and ferric salts newer method of exposure apply infrared radiation electrostatics and electrolysis The last three forms along with the diazo when developed by exposure to ammonia gas are referred to as dry processes as opposed to the more common wet processes which use liquids The basic camera techniques of photocopying are not so distinctive as is the mechanical equipment developed for use with the many photographic materials and the vast variety of their chemical characteristics

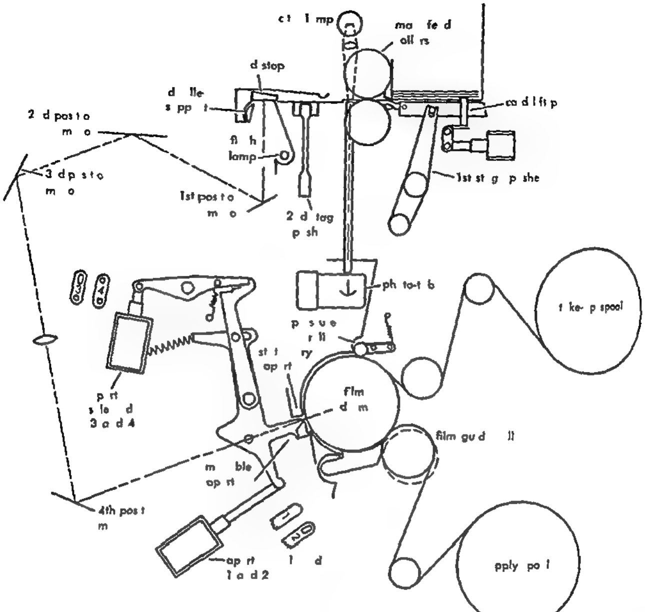
For a discussion of the development of photography and a full description of specific photographic materials *see* PHOTOGRAPHIC MATERIALS PHOTOGRAPHY

Photocopying is now applied in business offices and libraries in diverse problems of industrial production as well as in sophisticated data processing systems Advantages of photocopying are its photographic accuracy except for occasional problems with color reduction and enlargement ability of some processes speed in most instances space saving in the case of microfilm economy of labor and materials over any other short run copying process convenience of handling the thin flexible material as opposed to letterpress type or electrolytic plates simplicity of machine operation by untrained staff for certain processes and flexibility as achieved by the combination of photocopying processes with other printing processes

Photocopying processes may be somewhat arbitrarily divided into seven classes silver halide photocopying transfer processes thermography (



Fg 1 D g m f t p m ti phot p (Ph t t C p)



Fg ▪ D ag am of Li tomat c came a Flm apert e co t al (R dak Co p)

nically not photographic but a similar technique) plan copying electrostatic processes the electrolytic process and microfilming

The se en classes are not mutually exclusive because one may be used in combination with another This is frequently the case with microfilming in which the t ansparency may be the intermediate for enlargement to one of a variety of end products for example bound volumes printed by continuous xerography offset plates and multilith master Transfer processes and thermography are referred to as rapid copy or office-type copying because they are relatively or completely dry require no darkened laborator) and are mechanically s mple f r an office assistant to operate Facsimile reproduction is sometimes erroneously classed as photocopying when it is actually a mechanical or chemical transcription of electrical impulses generated by a photoelectric cell scanning device yet experiments are now combining this communications method with photocopying as the end process

Silver halide photocopying *Thi is the familiar technique which has been developed into variou forms including microf lm* The simplest is contact exposure of an original with negative or direct po i tive paper in front of a light box such a the photoprinting machines designed for making blueprints or whiteprints Add a nonadjustable bellow and adjustable lens and it approximates the hand camera such a the Le ca whi h has been commonly used to copy do ument since 1924 With an adjustable bellows it re embles the proce camera which i o admirably adapted t phot mecha ical graphic reproduction demanding enlargement reduction and excellent handling of tone

The next tage of ophi t cation u e a pri matic mirror t obtain a direct r ading negati e in tead of the usual in erted negati Sin t introd c tion in 1906 this has be n the m t fr qu ently u ed method of phot copying The l e t kn wn ma h nes are the Dexigraph Ph t cle k Ph t tat Re ti graph Ruther tat and Statma te (F g 1) S me

of these ha e fi d fo u or a e pable f nly l ght r ducti ns s me ut m t cally pro e cut and d v th p ts The m t elabo ate q ipme t n be u ed t m ke c py negati a d pri ts l d s, halft e prints f om olor transp rence cree ed Vel xes d stripp d in p t f r ph t off t c py (s PRINTING PLATE) In some m d l of dire t r adi g po t ve paper i po ble

Ph t c mpo i g i a pro s which erves a a t pes tt g ub t tut Ch r te s n a t an p re t urf e are b o ght to a rrect po iti n o e the py be ng m d l om de s thi p s ti ning i a c mpli hed by m ns of a pun hed tape c n t l wh h ndi ates lette s fa e po nt size and j t fi ti n A str b fi h p ojects the im ge thr gh app pr ate len nt the e st e l er film paper d fr m the d elop d film pl te pr p red u u lly f r gra ure o ph t l th g aphy S n e h a proce was first patented in 1877 m e th 50 a t chemes ha e b e pro p ed Mo t of the ma hine now lable u the t nd d typ it layo t fo n tial c mpo it on a d m t ha their wn c e t o units Th p oc l bee ed f r d t h f mot on p i re film Use i n w pape and m ga i e pr d t e pe lly f ad ri me t i n w mo t mm n

O pe i l appli ation f il ph toc pying th t m t h gh p d L t mati C m a devel ped n 1953 Th s ma h e phot gr ph data n t h l ti a d nd p l t in c l m a form n ll film the film n gat e then u ed fo pr ti g by photol th g aphy (F g 2) The p oc s i par t l l s t d i th p ep at n f di t r d th l t

f m th il r hal de t hniqu en prod c p es h g e ell t ra ge of nt ast re lu uperb t n o t nd th pe ma nc f r g p pe R l t ly peak ng it n t in p bit it qu l t h n t y i b n m tch d by a of th fi p b l w

Transfer processes T a fer pr a e f th ft gel t (r V tfa) typ d th d ff tsp B th of thes r fle nta t proc sse prod c p es that are ge e a y e p n ve th n pe b th il p o es but m expe tha th e f many f the other p c n th t f ll w d th q al t i b tt th n il mo graph d r lect tat p nt Howev th l good f t d th im g w ll de t r t tod f ye r B th p oc pa k ged n a ty f mpa t m h n s util ng a m bath t mb e d l pi g d fix ng h l et n g t ma k d degr th t met h i t c f t ally d el p d p pe

Th g lat t p tod d 1952 a ph li n f f d f m g l t n em l i n p nd g f h l d dy f rmi mp t d a h d n ng ag t Th V f m t p ocessed in a m t tl solut n i whi h th bl k d e f med tl gh t th g l t n but h d d o ly n th background area The wet matrix is pres ed against pl in paper to get the pos t ve copy from the unhardened dy By pre sing add t onal sheets f om two to nin add tional positi es may be ob tain d each fainter than the preced ng the proc ess can al o pr du e m sters for offset dupli ators and tr nslu ent copies f r diazo prints

The diff s on type ntroduced in 1950 uses a l e chloride emulsion on film or paper with the mage d ffused t opaque paper tran l cent p per or l ar film Th light ens tiv n gat e p pe afte xposur with the original is matched w th a hem lly c ated po iti e paper which i not light sen ti e They pass through a mon bath are squeezed t g the for 15-30 ec and are then peeled apart The un xp ed text a ea f the nega tive g es up ts u u ed silv r alts t the po it ve pape the eby om g in contact with th chemical c ting of the p s tive pap r to f rm a black im age G nerally m re than ne p t p r neg tive is not pos ibl Althoug mo e th n 60 different models si g this pr c s are marketed the es e tial diff n s a e in the m thod of hold ng the ori i al materi l to be copied i ghtly bound books b ing the major p oblem because t i d fficult to mak firm cont ct w th the l ght ource t the in ne margin The p c ss c n al o pr du e a two-d d p s t e c py on airmail tissue o translu t stock r on transparent film In 1959 a p jec tion am ra wa made a ail ble w th a high r peed en t zed neg t prov d ng th s p oc s with the ability to ha ge the s ze f the r g nal

Thermography Th s n t a phot g ph p oc e s be u e i stead f l ght it u th heat f i f a o r ys f exposur Yet this pro s s ail bl sin 1950 s conta t refl rapid py print ng pro s sim la in ts use to the t ansf r p oc s It a dir t p sit e proc ss—r o negat e is re t d Th or g n l copy mu t ha e ca b n or a

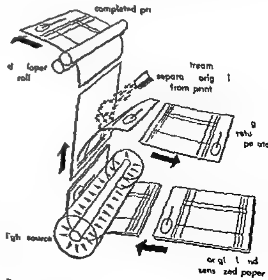


Fig 3 Fl w f g m f Wh t p t mo h (Ch l B g C)

metallic compound in the text ink to transform the radiant energy to heat and to effect the desired chemical change on the substance laminated between the transparent sheet of paper and the white waxy backing The heat sensitive substance undergoes chemical change and produces a black image lacking maximum sharpness It is a completely dry operation completed in about 4 sec finished copies remain sensitive to heat and can become increasingly dark It does not satisfactorily handle tone and the print is not as sharp as copies by most other processes because of the difficulty of focusing the long wavelengths of heat For inexpensive short use clean and rapid copying of correspondence or printed textual matter for informational purposes this process excels

Plan copying This is a simple contact operation using a number of possible chemical processes to print from a translucent original or by direct positive paper from opaque originals Materials used are so insensitive to light that powerful arc lamps must be used for exposure There is less of the usual wastage of materials in this process than in others The photocopying machine may be a glass tube box, or rotary drum device with a large surface to accommodate architectural plans engineering drawings charts maps or other such material Of the many processes the three following are common

Brownprint (also called sepia negative or van dyke) is an intermediate for making prints introduced in 1895 The material is paper sensitized with ferric iron and silver salts the first ingredient being the light sensitive material Exposure reduces the iron salt and when developed by immersion in water the ferrous salt reduces the silver salt to metallic silver Washing with a hypo solution removes any unreduced silver and leaves white lines on a brown background From this negative a brown line print can be made or a Phototracing can be made on paper having a wash off silver gelatin emulsion the image of which can be erased with a wet eraser and additions made in ink

Blueprint (also called cyanotype) dating from 1842 is a ferroprussiate paper sensitized with a mixture of ferric salt and potassium ferricyanide developed by immersion in water The result is white lines on a background of Prussian blue As with the brownprint the color of line and background can be reversed by printing from a translucent negative so as to make a blue line print

Whiteprint (also called dyeline or diazo print) dating from the 1920s is produced on diazo paper or film the emulsion containing a diazo compound and a coupling or activating component The process is based on sensitivity to ultraviolet light and development is by ammonia vapors or a liquid application (Fig 3) The use of this method to produce translucent film originals from which multiple prints can be inexpensively made on paper has been a highly developed technique Indeed despite the fact that the image will deteriorate somewhat over a period of years this process has largely superseded the familiar blueprint chiefly because of better appearance easier use for notation somewhat better quality and comparable cost

It should be added that small diazo-process machines are available to copy letter size materials and pages from bound books When limitations imposed by the material to be copied can be overcome the excellent sharpness of a diazo print and its exceedingly low cost make it competitive with the transfer process

Electrostatic processes There are three distinct dry photoelectrical processes producing positive copies without a negative intermediary xerography was invented in 1937 Electrofax was announced in 1954 and Smokeprinting was patented in 1958

Xerography is a printing method using a photoconductive plate having an electrically conductive backing material coated with vitreous selenium When the plate is precharged to a 6000-volt screen potential by a corona discharge which imparts a uniform electrostatic charge the coating becomes sensitive to light and the charge is dissipated to a ground by light rays reflected from the white parts of the document being copied The sensitized plate may be exposed by contact by projection or in a camera to achieve enlargement or reduction The latent image is the remaining positive charge which attracts negatively charged black powder (a mixture of a carrier and a resinous pigment) which is then heated and passed to paper on which it is fused A resolution adequate for most textual matter can be achieved and recent developments have improved the handling of continuous tone Experimental work has been done on the use of color and in the depositing of images on copper laminate and on clear acetate sheets for lantern slides Besides its use for enlarging microfilm some of its important uses are for making translucent negatives for diazo printing paper and metal plates for offset lithography and masters for spirit duplicating (Fig 4)

Electrofax is similar to the xerographic process except that it substitutes an electrically charged paper on which the copy is printed for the selenium coated plate The paper is coated with a thin layer of special zinc oxide in a resin binder and it is sensitive to light only after having been given a negative electrostatic charge upon entering the machine it can therefore be stored without deterioration for long periods before being used The finished print is exceedingly stable Experimental work has been done on many applications similar to those of xerography as well as on satisfactory treatment of half tone and continuous tone production of relief printing plates use as a dry offset process and on electronic typesetting at 2000 characters per second under control of magnetic tape or punched paper tape The process appears to be intrinsically more flexible than does xerography

Smokeprinting is a process which deposits electrically charged particles on paper or other material The paper is held behind a sheet of glass

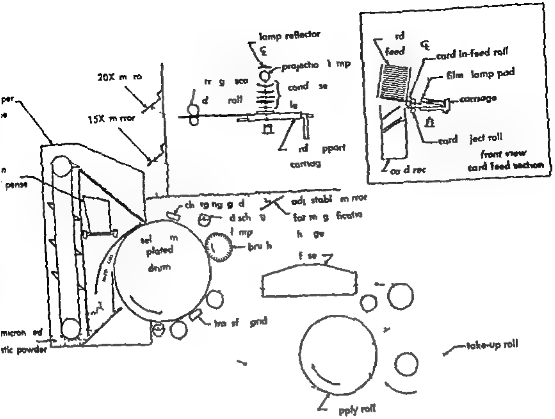


Fig 4 Sch m t d g m f t u b nt f t d m film m t d o p rtu d (H l d m flm a l g m t (l ef) Fe d me h sm f X)

wh h ı ba ked with thin metallic atı g Th m t f pa ticl ıs d p sed from beh nd the pa pe by an ele trode which g e ıt ha ge A po t e o eg t e prı t e be mad d pe d ng upon the m k material u ed nd whether ıt ı charged po t ly o negat ely E pe ment l wo k h s bee suc essful n a Vert al Step and Repe t Mı c filming Came a f n odu ıng m crofilm m g s on sh t film a d n th Photro ıc Reprod ce for mı rofilm enla g me t.

Electrolysis Electr lys s ha been applı d to ph tocopyı g nde a pr ces d elop d ın 1957 The expos re ı mad by projection on a sh et consı tı g l a p pe support, a thin alum num lam ı ate and a c tıng of a wh te ph toconductive s b- t n e A d p t ı al appl ed cro s the el ctrolyte d the l mınum nderl yer are ne e ary f r de l pment whı h ı th gh ntact th the elec ı l t d the by p od e th ım g on th e posed urf ce by lectr ly s A po t e mage produ ed fr m g t e mı ofilm p jecı be a the light expo r e es th ph toc d to to l se res t n e resultı g ın l tr ly t kıng pl e ın xpo ed athe than n n po ed as.

Microfilming Th doc m t ry produ ı proce Th fir t pat nt f r a e mm ıal ap- pl t w s g ted ı 1859 alth ıgh wide ppl ti d tes fr m 1928 A m film c py m y be d fi ed t p t ph tocopy t r duct n f ı t th t pt l nl gem t q red f r tmal r d g nd w th r sol ng pow r uffic ent for e r te se ord ng of t xtual and tonal de- ta l Norm l edu tı ns a e f om 12 to [illegible] d ame ters alth gh 100 dıameters s feasible Res lv g p we ı w ll er 100 lines/mm—generally about 145 lines/mm f r g od p ıt n film 160 lines/mm for good mı rofilm len es and 180 line /mm for g od neg tı film Em lsions gı ı g 500 l nes/mm a e being d vel ped Such a micr ph t graph ıs d stingu hed from a ma rophotogr ph which ıs a c py ne th n ıginal s n as ın all the proces es described abo e

The microfilm ıs comp sed of a slow speed pan chromatic emul on on a mechanic l base f cellu los etate (nitro ellul n h s unacceptabl qual tıes) In the Un ted States t generally ı no long r u ed w th p rfo ated edg ın ord r that bet te u e m y be made f the film width Pos t ve e p m y be m de from ıl e n g tı es by con [illegible] t prı t ng o s l e Kalfax film r s metıme p p r Da film n d f r e a t dupl atı n of lve ll film g t e-to n g t or p t to-pos t prı t Th s three emuls ons a l abl n the omm 35-mm roll f tm nd l ın lls of 16 *mm* for mate al su h as b nk h ck wh h ha e fi det l 70 a d 105 mm f r mate al s ha gı e ring d aw ng a d flat h et [illegible] 7½ by 12½ cm and large s es wh h ha fil ıng a d a ch ng d t g

Kalfa microfilm a ariant use of dı zo which n e p u e e t g bubbles wl h form tl e ım age by c tt ı g the light Kalfax (u d ı

1955) is a plastic emulsion on a polyester base Upon exposure to ultraviolet light the photosensitive compound in the background area decomposes in the thermoplastic vehicle with one of the products being nitrogen gas When the film is developed by heat (for 2 sec at 255 F) the high pressure created by the gas blows microscopic air sacs and fixation by ultraviolet light stabilizes the compound by permitting the nitrogen now created in the text area to diffuse out of the emulsion in about 8 hours The air sacs serve to scatter the light falling on them during projection for reading Where they do not exist to scatter the light the compound casts a shadow which forms the image

Microfilm is very inexpensive of materials is valued as a substitute for deteriorating paper and for the space and weight it saves over full size copies is advantageous as a flexible intermediate and has the physical properties of other silver and diazo copies In any application such as those described below detail will be lost increasingly the more distant the generation is from the original (that is original copied to negative copied to positive copied to a second negative equals three generations removed this loss being estimated as roughly 30% in each generation

Equipment for microfilming is specialized because of the exacting requirements Cameras have exceptionally fine lenses and may have a flat bed or rotary feed and be manual or automatic in operation Similarly processing equipment varies from hand fed deep tanks to large automatic machines adapted from those designed for motion picture film Reading machines are also available in considerable variety

Besides the advantages of microfilm in its own right other applications and specialized technique have brought microfilm to a high state of technical development These may be classed as enlargement techniques publishing techniques and data processing applications

Enlargement printing both individually of single frames and automatically and continuously of rolls of frames can be accomplished by any projection process Enlargement is possible from frames selected while viewing microfilm on a reading machine by the inclusion in the machine of a device for producing an electrolytic copy or a silver halide copy developed in a monobath The most advanced automatic enlarging machine is the Copyflo which was first available in 1956 This xerographic enlarger makes photocopies from negative or positive 16 mm or 35 mm microfilm as well as from original documents at the rate of 20 ft/min on rolls of unsensitized paper up to 11 in wide

Publishing of opaque microtexts is accomplished by three variant edition processes Microcards proposed in 1944 are photographic prints $7\frac{1}{2} \times 12\frac{1}{2}$ cm in size prepared from 16 mm or 35 mm film commonly at a reduction of 20 diameters with indexing data legible to the naked eye at the top of the card Readex Microprint is a somewhat similar product on 6×9 in cards but is prepared from microfilm and printed by offset Microlex is similar to the Microprint in appearance but is a photographic print from a sheet negative (microfiche) made on a step and repeat camera and two positives containing consecutive pages are laminated back to back Microfiche is the name applied to transparent forms of microtext in various sizes of sheet film it is not an edition process

Data processing has used microfilm in the unitized strip and roll form Unitized film is roll film cut and handled in units of single frame whereas a film strip is roll film handled in length of 2 10 frames diazo film is commonly used for making copies Both unitized and strip film are commonly mounted in or on cards having indexing information which is readable to the naked eye and if the card has a rectangular hole through which the film may be viewed it is called an aperture card Two versions using a different technique are Micro trip, which is an opaque paper strip printed from microfilm and having a moisture type adhesive on the back and Microtape which is similarly an opaque strip but has a pressure sensitive adhesive Much special equipment is available for mounting viewing enlarging and duplicating film mounted on aperture cards and use of such cards with tabulating machines has become a common application of microfilm In unitized form film has reached its most sophisticated application in the Minicard system which automatically searches units of film 35 mm by 16 mm in size containing both textual matter reduced at 60 diameters and digital information for photoelectric eye selection Roll film is also being applied in data processing systems an early device was the Rapid Selector developed from principles suggested by Vannevar Bush in 1945 and a more highly developed machine is the FLIP (Film Library Instantaneous Presentation) which upon instruction from a keyboard punched card or magnetic tape automatically locates and projects for viewing coded frames within 1600 feet of film See PRINTING [D C W]

Bibliography H W Ballou *Guide to Microreproduction Equipment* 1959 C M Lewis and W H Offenhauser *Microrecording Industrial and Library Applications* 1956 *Manual on Document Reproduction and Selection* FID Publ 264 1953 and continuation H R Verry *Document Copying and Reproduction Processes* 1958

Photodiode

A semiconductor two terminal component with electrical characteristics that are light sensitive All semiconductor diodes are light sensitive to some degree unless enclosed in opaque packages, but only those designed specifically to enhance the light sensitivity are called photodiodes

Most photodiodes consist of semiconductor p n junctions housed in a container designed to collect and focus the ambient light close to the junction They are normally biased in the reverse or blocking direction the current therefore is quite small in the dark When they are illuminated the current

ı p p t nal t the m t of l ght fall ng on th ph t d ode F r a d u n f th pr p rties of p n j ct n a JUNCTION DIODE

Ph t d odes a e u d b th t d t t th presen of l ght and t m asu e l ght ı ten ty S PHOTO ELECTRIC DEVI ES [W R S I]

Photoelasticity

An p r mental techn q for th m a srem t f t es and t ans n m t r al b j cts b y m a f th ph n men n of m h n al l refri gen Photoela ticity i e p ally f l f r th t dy f bj ct with irr g la bo da ies and tres con cent ati n au h g ces f m h n ry with n tches r c rv tru t ral mpo ent with l t r h l a d mater al with rack Th meth d prov d u l m an of l r v ng ov r all tres h racteris t c f n b j t b y m a f l ght pat t rn pr j t d n er n r ph t g aph film R g f atres n entrat n can be det rm d n gener l l y mpl l r ve ti n H wever pr s a ly s f ten i n c mp ex n a d b ar tres a d t n t a y po t i a b j t requ es m re m l ed t h q ues Ph toel t ty g n r lly d to t dy b j ct tres d i tw pla ar d r t n (b ax al) b t with ef m nt t an l d f r obj ct tres ed n thre p ti l d ert n (t i l)

F r t a al t d es m d l ge m et ı ally mi la t th obj t t b an ly ed i pr pa d fr m h et f r l tran parent m ter al d l l d th b j ct w ld be l d d

Use of birefringent phenomenon M l l mate l mm nly d f r ph t el ti ty are B k l t ll l d g l ti ynth t re ns gla and th ommer l p l t that r pt lly en l t r e s d tr in Th mat ri l m t h v th pt l p perties f p la g l ght when d t e (pt al t ty) a d f tra m tting t th pr n p l t ess pla w th l oc ti d pendent n th t (b f ng n d l l r f r ct n) In dd t n th materi l h ld be l r l sti h m gen pt ally tr p hen d no tre tran and ally f f m creep g g and dg d t rb n es

When th t d m l l ı b j t t m h m t p l ed l ght n p la ec r th l r f g l th m d l th l ght t m rg ir t d i t tw th g l pl n f l o CARRIED LIGHT) [illegible] a th l tt f l ght p op g r d ff e t n ea h d ct ther th s h f ting l th l ght w ve When th wa es m d w th th g l pe r g on f t es wh re th wa ph ses ca l ap pe l l [illegible] d r g n f tres wher th w ph m l ı ppe l ght Ther f m d l f mplex t d t l l l ght and d rk fr ng p tt r (l och m ti fr ng) are pr l t d f m th m d l Th fr g rel t d t th tr

When wh l ght ı sed pl f m noch m tic l ght th r l tr et dati n f th model a se th f i g t app ar in l f th pec t m Whit l ght s ften u l f r dem n t ti n d m ochr mati l ght ı u l f p r m asu m nt

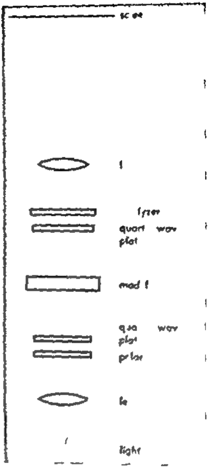


Fig 1 Ba ic ph toelastic pola scop

Polariscope A l p l ct g l n g l t l ti ty ha a l ght (g r lly m ochr m t ı a ll m t ng l a p l r zer and a q r t r w e plat (Fig 1) Th g l t i l irefring nt m t al th t s th r l t e r t rd t of l ght t be exa tly n q rter th w el ngth l th l ght Next n th gt l s th is a plan r m d l f th b j t n l er t t a d t e l in th d r t on f th pl n Fi lly there at a d q ar t r wa pl t p l ri all d th nalyzer a foc i g len nd a v ewing scr en r f lm Many ari t n f th l a t n mi n type appara t ar n Other len may be a ld d and m p n nt arra g d If ppr p at m rr r ar a ld d th pol r ope n rt to a d l l ng type wh h is u f l f r th tudy f thi m d l und r l w tr th n mber f fri ges d ll

A typ al such mat f ng patt rn sh w th ff t flat pl t with t al h l p ll d t th upper and l wer end (F g 2) Th ng t n f fri ges t th bo nd ry f th h l ind t s reg f tress c ntr t n typ l f tres fieh or at t t T tudy th exa t stres at a g en p nt in th m d l th m d l is g ad lly l ad d (f m d t n of n l ad) d th num

1955) is a plastic emulsion on a polyester base. Upon exposure to ultraviolet light the photosensitive compound in the background area decomposes in the thermoplastic vehicle with one of the products being nitrogen gas. When the film is developed by heat (for 2 sec at 255 F) the high pressure created by the gas blows microscopic air sacs, and fixation by ultraviolet light stabilizes the compound by permitting the nitrogen now created in the text area to diffuse out of the emulsion in about 8 hours. The air sacs serve to scatter the light falling on them during projection for reading. Where they do not exist to scatter the light the compound casts a shadow which forms the image.

Microfilm is very inexpensive of materials, is valued as a substitute for deteriorating paper and for the space and weight it saves over full size copies, is advantageous as a flexible intermediate, and has the physical properties of other silver and diazo copies. In any application such as those described below, detail will be lost increasingly the more distant the generation is from the original (that is, original copied to negative copied to positive copied to a second negative equals three generations removed), this loss being estimated as roughly 30% in each generation.

Equipment for microfilming is specialized because of the exacting requirements. Cameras have exceptionally fine lenses and may have a flat bed or rotary feed and be manual or automatic in operation. Similarly, processing equipment varies from hand fed deep tanks to large automatic machines adapted from those designed for motion picture film. Reading machines are also available in considerable variety.

Besides the advantages of microfilm in its own right, other applications and specialized techniques have brought microfilm to a high state of technical development. These may be classed as enlargement techniques, publishing techniques, and data processing applications.

Enlargement printing, both individually of single frames and automatically and continuously of rolls of frames, can be accomplished by any projection process. Enlargement is possible from frames selected while viewing microfilm on a reading machine by the inclusion in the machine of a device for producing an electrolytic copy or a silver halide copy developed in a monobath. The most advanced automatic enlarging machine is the Copyflo, which was first available in 1956. This xerographic enlarger makes photocopies from negative or positive 16-mm or 35-mm microfilm, as well as from original documents, at the rate of 20 ft/min on rolls of unsensitized paper up to 11 in. wide.

Publishing of opaque microtexts is accomplished by three variant edition processes. Microcards, proposed in 1944, are photographic prints $7\frac{1}{2} \times 12\frac{1}{2}$ cm in size prepared from 16-mm or 35-mm film, commonly at a reduction of 20 diameters, with indexing data legible to the naked eye at the top of the card. Readex Microprint is a somewhat similar product on 6×9-in. cards, but is prepared from microfilm and printed by offset. Microlex is similar to the Microprint in appearance, but is a photographic print from a sheet negative (microfiche) made on a step and repeat camera, and two positives containing consecutive pages are laminated back to back. Microfiche is the name applied to transparent forms of microtext in various sizes of sheet film; it is not an edition process.

Data processing has used microfilm in the unitized, strip, and roll form. Unitized film is roll film cut and handled in units of single frames, whereas a film strip is roll film handled in lengths of 2–10 frames; diazo film is commonly used for making copies. Both unitized and strip film are commonly mounted in or on cards having indexing information which is readable to the naked eye, and if the card has a rectangular hole through which the film may be viewed, it is called an aperture card. Two versions using a different technique are Microstrip, which is an opaque paper strip printed from microfilm and having a moisture type adhesive on the back, and Microtape, which is similarly an opaque strip but has a pressure sensitive adhesive. Much special equipment is available for mounting, viewing, enlarging, and duplicating film mounted on aperture cards, and use of such cards with tabulating machines has become a common application of microfilm. In unitized form, film has reached its most sophisticated application in the Minicard system, which automatically searches units of film 32 mm by 16 mm in size containing both textual matter reduced at 60 diameters and digital information for photoelectric eye selection. Roll film is also being applied in data processing systems; an early device was the Rapid Selector, developed from principles suggested by Vannevar Bush in 1945, and a more highly developed machine is the FLIP (Film Library Instantaneous Presentation), which upon instruction from a keyboard, punched card, or magnetic tape, automatically locates and projects for viewing coded frames within 1600 feet of film.

See PRINTING. [D C W]

Bibliography: H. W. Ballou, *Guide to Microreproduction Equipment*, 1959; C. M. Lewis and W. H. Offenhauser, *Microrecording: Industrial and Library Applications*, 1956; *Manual on Document Reproduction and Selection*, FID Publ. 264, 1953 and continuation; H. R. Verry, *Document Copying and Reproduction Processes*, 1958.

Photodiode

A semiconductor two terminal component with electrical characteristics that are light sensitive. All semiconductor diodes are light sensitive to some degree unless enclosed in opaque packages, but only those designed specifically to enhance the light sensitivity are called photodiodes.

Most photodiodes consist of semiconductor *p-n* junctions housed in a container designed to collect and focus the ambient light close to the junction. They are normally biased i[illegible] r e or ing d recti n the curren [illegible] qui in the [illegible] When the

ι proport n l t the amo nt f light fall ng on the ph tod de F r a di u n of the p ope t e of p n j nct s ee JU CTION DIODE.

Ph t d d are u ed b th t d tect the pre nc f light and t mea r light ı tensity Se PHOTO ELECTRIC DEVICES [W R SI]

Photoelasticity

An xp r mental techniq e for the me ı e ıent f tre s s a d t a s in mate ı l bje ts by mean of the phe menon f me hani al bı ef ngenc Photelast ıt ı esp ıally u eful for th t dy of bj cts w th rr ul r b nda ı and tre c n e t at s h a p e e of machin ry w th not h o rve t tur l mpon nt with l ts or hol a d m t ral w th r cks Th neth d pr ıde a al me ns f ob erving o r all tres hara t r st s of an obje t by m a s of l ght pat t s p ojected n a creen r ph togr pl ı film Reg f st co c trat on e n be determ ed ın ge ral by ımple ob ervat o H we er p ecı e an ly ı of t mp e a d hear t e e and t s at a y po nt n obje t requ re more n l d te hn q e Ph t ela t c ty ı gene ally ed t tudy l ject tr d ın tw pl nar d e t n (bia l) b t with refinem nts t can be u ed fo bje t tres ed ın th e pati l direct ns (tr a l)

F r b a l st d a mod l ge metr c lly s m la to the bj ct to be a lyzed ıs p ep red f om a t of p l t a p e t mat al a d l aded the bj t w ld be load d

Use of birefringent phenomenon M d l mate l e mm ly u ed f r ph t l tı ty a e B ke l t ell l d g latin synthetic e ns gl a d ther omme c l prod ct th t a optı ll t e t t e s d t n Th mat ı ls t t h the pt c l pr p rtı f p la ız ng l ght when der st s (ptı al e tı ty) and f t an mitt ng t n th pr ıpal t e pl ne with l tıes de p d nt n the tre e (b f ı gen d ble ref act) In addit n th m t ı l hould b cl ela tı h mo neo opt cally tr p c whe d o tr t a a d rea n bly free fr m ep g ng a d dge d tu ba e

Wh th t d m d l bject ı mo och om t c p la d l ght p la e p th b re fring n f the mod l se th l ght t m g f s ted ı to t th g n l pl (s POLARIZED LIGHT) Bec u tl el tıe of l ght p p g t r d ff nt h dı t th re a ph h ft g f the l ght w ı Wh n th w r mb d th th pol t pe e g n l st wh r th w v pha ancel p p a bl k d s f t whe e th w phase omb app r l ght Th ref ı m d l l mpl t d trıb tı l ght and d k frı g p tt l och m t f ng l p o ı ted f m th m d l Th e f ng r lat d t th st

Wh wh t l ght d n pl e f m chro ı l ght th lat t rdat n f the mod l the f ı g to appe l f th spectrum White l ght fte u ed f r demo tratı a d m ochr matı l ght ıs u ed for pre ı m a u em nt

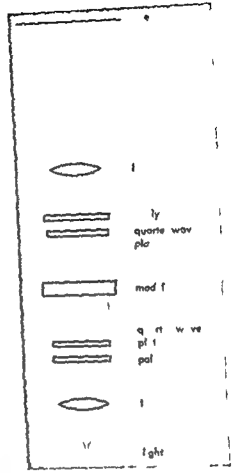


Fig 1 Bas phot l t c p l op

Polariscope A b ı poları p u ed photoela t ty ha a l ght rce (generally mon chrom tı) a ll mat ng len a pola ı e a d a quar t r wa e plate (F g 1) Thı plate ıs birefringent mat r al th t uses th relatı retardat n of l ght to be a tly o q art th w ı length of th l ght N xt th pt al path ıs a pl nar m del f th bj t u de te t nd t e ed ın th dı ec t o of th pl e F nally the re a ond qua te w e plate a p la r call d the nalyz r a f c ng len nd a v ew ng e een film M ny s atı of th b s tra sm on typ app t are ı n Other l n e m b added and m p n nt r arranged If app opr at mirr s are add d th p lari pe o ts to a d ubling t pe whı h s u ef l fo the st dy of th m d ls u d r low stre s the n mb of fr ng d ble

A typ al ıs ch m t fringe pattern h w th ff ct o flat plat with a ntral h le p lled at th ppe a d lowe e ds (F g 2) The ges t f fr ng t th b u dary of th h le ınd cate a g n of t con entratı typ l of st e s b ha ı at cuto t To t dy th exa t stress at a g n p nt ın th m d l the model ıs grad ı lly lo ded (fr m a d t o f no lo d) nd the num

ber of fringe changes (fringe order) at that point is observed. Special equipment is sometimes employed to obtain partial fringe orders and to sharpen vague fringe boundaries. The fringe order is directly related by *a calibrated constant to the* difference of the principal stresses at that point.

Determination of principal stresses. Shear stresses can be related mathematically to the difference of the principal stresses, thereby relating *shear stresses directly to fringe order.* High shear stresses often cause the material to yield or fail, so that a point of large fringe order indicates a point of potential failure. In many applications of photoelasticity a knowledge of shear stress is all that is needed. This fact makes photoelasticity a simple and direct tool for investigation of complex stress systems. However, if principal stresses and their *directions are required, additional experimentation* is necessary, as described later.

Isoclinic fringes are a different set of interference patterns made by using white light, removing the quarter wave plates and rotating the polarizer and analyzer a fixed number of degrees. These fringes represent lines making known angles with the principal planes of stress.

Stress trajectories are lines of principal stress directions over the model, obtained graphically from the isoclinic fringes. Stress trajectories are not lines of constant stress.

The determination of the principal stresses requires additional information, which may be obtained in several ways. Principal stresses are determined analytically by differences of the shear stresses based on equilibrium equations. This procedure requires a numerical point-by-point study of the model, utilizing the shear stresses and stress trajectories. Principal stresses can be found analytically or experimentally by solution of Laplace's equation of elasticity (*see* ELASTICITY). In principle, this procedure supplies equations pertaining to the sum of the principal stresses at any point in the model. Utilizing equations for the difference of the principal stresses from the isochromatic fringe orders, the stresses may be found by solving the two equations for the two principal stresses. Principal stresses are found experimentally by measuring the changes in thickness of the model under stress. Because thickness changes caused by the Poisson's ratio effect are minute, a sensitive measuring device, such *as an optical interferometer*, is needed, although direct-reading thickness gages are sometimes used. The interferometer produces fringe patterns called isopachic fringes. This method essentially provides information regarding *the sum of the principal stresses* as with Laplace's equation. Another experimental method is to pass polarized light obliquely to the surface of the model. The relative retardations of the light produce interference fringes. These oblique fringe orders can be related to the principal stresses differently from those obtained by isochromatic fringes. Using the information on stresses from the isochromatics in conjunction with the oblique relations, the principal stresses may be obtained.

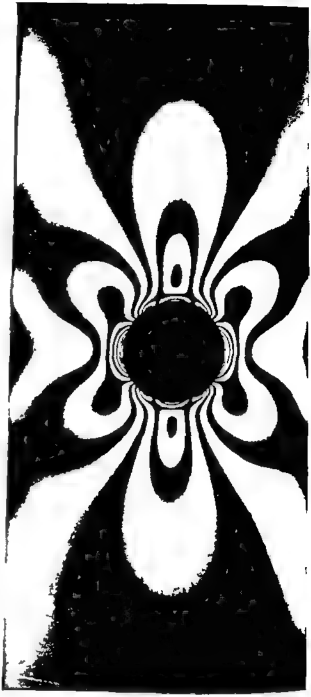


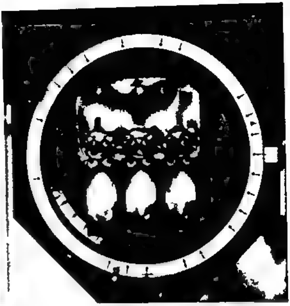
Fig. 2. Isochromatic fringe pattern for plate with hole. (From M. M. Frocht, Photoelasticity, vol. 2, Wiley, 1948)

With care, stresses determined by photoelasticity are 98% accurate. With stresses determined, strains may be easily computed by elastic relations.

Three-dimensional measurements. Three-dimensional photoelasticity is also possible, although the technique and stress-*strain relationships* are more involved than for planar objects.

The frozen stress method is well suited for *three-dimension studies.* Certain optically sensitive materials, such as Bakelite, when annealed in a stressed condition, retain the deformation and birefringent characteristics of the initially stressed state when the load is removed. A three-dimen

Typ l t p tt pl tc mod l w d d p l d l ght (B h & L mb Opt l C mp y)



St t t pl t model f oots f t m t b bl d d m l t d ope t g d t (W t gh El t C p t)

St d t b t d l h t d tw w ts g ph t t t h q Pl t ph t l t t g m l t l p m ll w t dy f t l m t l p t th th f pl t m d l Th p m ty f l f g th ty f th w t l d t h gh tr th t g (B H ll M m l l t t)

nal model may th efore be ut up i t slice Thes lices m y then be analyzed ndividu lly on mewhat the s m p ne pl a a e the planar mod l

Th catte ed light t hn qu m y l o be used (r th e-d men on model u h as to on bar Th tt d l ght pr n ipl i based n th fa t that p la ed l ght pa g thr ugh b refr gent m teri l att r n a predi table ma ner acting s a pt l a alyzer in a p lar cope

Measurements on actual objects Th Ph to-Str m thod is tually ariati n f th nor mal p la t pe A sheet of bir fr ng nt material bo ded t th pol hed u f ce f the a tual ob-je t to be st d ed w th pola izer a d quart r wa e plat i terp ed bet een the light and the b-j t. The l ght (u ually wh te l ght) pas es thro gh th t essed b efring nt mater l a d i refl ct d ba k th ou h th quarter wa e plat and the po-la zer (h h n w a t a n n ly e) I hro-m t c fri g a p ojected as i a n rmal p lari p D pe d t n g od bo d ng between the b ef g t m te l a d the t d bject Pho-t St ess the d ntage th t t n be u ed on a t l t u tu es d r serv c loads w th ut be ng redu d t m d l f rm It may b u ed to find s r f e t and trai s on c rved r thr e-d m n on l bjects Alth ugh ph toela t ity gener lly l m ted t el t b h vior Ph t St e s m y b ed t d t rm e the n) tic str s (but n t t s) of bjects p o ided th bonded pt c l m t ri l ema n el t c The te hniq may also b ed w th nh te og n u m t rials uch s wood a d c ret

Dyn mi ally nd ed stres s a d tr i may lso b stud ed by ph t ela t c ty whe h gh p ed m t pi t re me a r ed t ph t graph th fr patt s *See* STRESS AND STRAI [W.Z.]

Bibliography E G Coke and L N G F lon *A T e t Photo El st city* 2d ed 19 7 M M F ocht, *Phot la t city* 2 l 1941 1948 M I Het yi (ed) *H dbook of Exp rim tal Stress Analy* 1950 G H Lee *A Int duct n t Ex p rim t l St A alysis* 1950

Photoelectric devices

Dev ces whi h a e gnifi ant and eful hange i lectr l ch t i t cs s c sed by ident d t e gy While all mate i l a e n ri e t ct w th el t magnet ad t n to som de-gree ph t el ct i devi th b t a ig fi t n ti ty wh h a be d t d t i m a u e r tt th n d nt d i o Ph t sen ti ity h e n mpl es th nfr ed and ult I t e t o f the t um s w ll the bl S PHOTO-ELE TRICI Y

Ph s lect d e t w th th n d nt d t n i ty of w y In ph t du t e ph t es t c lls th sta a de-p d g p n the i t ty nd wa l ngth of th t d t n these ll r rti ul ly s i n th f ed n f th p trum (s PHOTO-CONDUCTIVE CELL) Ph to oltaic cell ometimes called photronic or bo indary layer pl otocell gen erate an utput olt when excited by photons of l ght A ariety of phot lta c cells are available t cover section f the infra ed and ultravi let re gion as well as the i ible When l aded with a l w impedance f about 1000 hms or le the ra t o between the l ght input and current output i l nea nd the frequency *respon e of th sy tem i* fai ly flat to about 2 kilocycles per econd When the cell is open circu ted the voltage outpi t in crease logarithm cally with light input *See* PHO TOVOLTAIC CELL.

Photod odes and ph t t an sto s e ph to ol taic devices in which the junct o barr er height i modulated by inc dent light In the photod ode thi a ses the *rever e cur ent to vary* as a functi n of the light inten ity and back voltage while in a t *an i to it can b* employed as the input or injec t n gnal t a fixed b a ed circu t or u ed to vary the bias cond ti n See PHOTODIODE; PHOTOTRAN SISTOR [D B K]

Photoelectricity

Vi bl l ght *or other electr mag et c* radiat on i e d t on a olid liquid r e n liberate elec *tric charge* whi h move in an electri fi ld th s process is called phot electric ty Th t rm in cl de three di ti ct phe mena a f ll ws

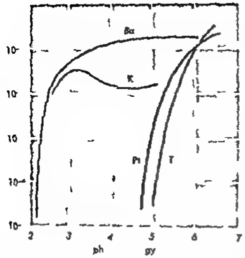
1 In th *e ternal* phot el ct c effect often c lled photoem si n and fir t expl ined a quan tum ba by Albert Ei ste n ele trons re eje ted *from a s l d (o liq id) s rface i to a surrounding* cu m the common multiplier ph totube depend up n this effect

2 In a ga el ctr ns and pos ti e ion m y be produ ed in the proc s known as ph t ionizat on An pplicati n of this is m de in the use of i niza *t on chambers* to d tect x rays

3 Mobile electr ns nd posit e h les which remain i side a sol d may e ei e either to photo-conduct n r the ph to oltaic effect Photocon d *ctio* is u ed in television came tube in elec trical duplicating proce ses and in co trol devices *(wh re a simple* ternal b ttery fur ish s the elec tric *pow r)* The photovolt cell is a energy c nve s on de ce wh h fu n hes its own power It i sed f r example in ph t graphic exposure m t r nd in sol batte i s

In addition to the th ee ph omena j t de s bed the *e i an i* tern l ph t electric pr e n n tom c ll d th A g r ffe t or ut i n za ti n A p rt f th ab rpt n of x rays c n be at t buted t th *Aug r* eff ct which in ol s ph to-ele t absorpt *on of* the x ay qua t with re-s lti g eje ti n f electro s f om th at m X ray b pt o al occ s by ph toel t x t t n and by fluo e cen e

F nally the e i the ve s ph t el ct ic effect which i mply the n r f th n mal phot elec tric proc In thi ff ct n elect b bed by l d a d phot n em g The in e e pho-



Fg 3 Sp t l d t b t f the ph t l ct y eld f m typ l mpl f ba m (B) p t s m (K) pl t m (Pt) d t ll m (T) Plat m d tell m h p t lly the ame l ct o wo k f t Not th h ghe th h ld d m t ply g rv f tell m wh h typ l el m t l m d ct

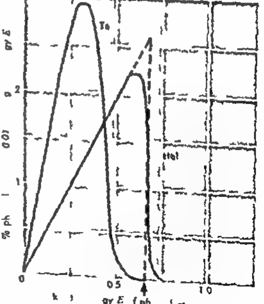
l t c pled t the inte n l pe i d p t n t l

E t ime t l d te mi ti f th lat m p rta f f e nd v l me ph t effe ts n met l s d ffic lt F p m t ly H M d h s oll b t nd at that f r pot s um th l m ff t p ed mi t f r ph t n ene g f m th thr h ld alue at 2 1 to at le st 4 e Th th ph t l ct m s n e se tl th k of a p t um film e (Th w ld n t be tr f th u fa e eff t) Ph t l t n c e pe f om d pth gre t than 10- m wh n e t d by light n th th h ld e g

Th s fa the ph t l t th h ld b b en t ted h ply d fi ed q a t ty Th s pr c ly t fo met l ly t t mp t r r ab l t At h gh t mp t th uppe d f th b nd of ic up ed le tr en gy state F g 2 n long h p lt b c me d ff b u f th rm l git t Ele t o s m y be th n ld l φ At d ry m t mp t f r ampl m a ur bl ph t m n pp f r ph t g a m 0 2 b l w the th h ld R F wl d v loped e nt g aphi l tech q k w F wle pl t f det m g th b l t e th h ld f m d ta tak t h gh t mp e r n th p t l d pe de c f th ph t le t y ld h h s the n mbe f ph t f t l t d p d t ph t L A D B idg h d el ped m f t h q n ng the th tempe tu d p d e f th ph t lect yi ld th d r b r f ph t el t s en g at fi ed f eq y The t t n t h w th t th ph t el ct y eld i appr m t ly

pr porti nal t th quant ty $(h\nu - \varphi)^2$ when the phot n energy h is within abo t 1 ev of the thre h old n rgy φ Figure 3 h w a graph f the spec tral d pe dence of ph t ele tri yi ld f some typical em tters Figure 4 sh ws typical nergy d tributi n Ph to l ctric yields from m tal are of the rd r of 10 l ctron pe incident ph ton wh n $h - \varphi$ t 1 e Ph toelectric thresh ld en erg es r nge fr m fo e sum t values uch a 5 ev fo plat nu n They ary for d fferent types f c y tal fa the s me cry tal and are e r ed ingly en tive to m ll traces f adsorb ed ga

Semiconductors The ph toelectric behavior of emc d t r uch as germanium or t llurium diff r fr m that f metal A fown in Fig the ele tro s t a emic d cting emitter compl tely o cupy a cl ed ba d of ene g es which li s j st below a o- all d f rbid len energy band (se BAND THEORY OF SOLID) The electron f have qu te diffe ently fr m tho e in m tals As a result the ph toelectr c thre h ld e ergy φ is larg r than the electron c w rk f n tion Thus a s m condu tor exhib ts a h gher photoelectric thre h ld n rgy than a metal ha t g th same work f ncti n An e ampl f thi i sh wn f r the m tal plat num and th semi nduct r tellurium in F g 3 B th th s pa ticular pl ti um ampl (Pt) and the tel lur um (T) l e th ame el ct on c w rk func tio about 4 8 ev The ph toelectr c th e hold f the platin m i equ l to the wo k fun tio whereas th t f r the t ll rium s cl rly higher Another d ff e ce between semi ndu t rs and met ls e ident f m Fig 3 The phot ele tr y eld f m



Fg 4 gy d t b t of ph t l t o s f m t llu um d f m m t l h g th m w k f ct Th s f d l f th m t l h ws lt f d ry m t mp t o d th d sh d l f b l t Th o w mo k th E t n ma m m gy Th ph t gy 5 42

toelectric effect is not commonly investigated because it is an extremely difficult process to measure. *See* AUGER EFFECT; PHOTOCONDUCTIVITY; PHOTOEMISSION; PHOTOVOLTAIC EFFECT; *see also* COMPTON EFFECT. [L. A.]

Photoemission

Photoemission, also called the external photoelectric effect, is the ejection of electrons from a solid (or less commonly, a liquid) by incident electromagnetic radiation. The visible and ultraviolet regions of the electromagnetic spectrum are most often involved, although the infrared and x-ray regions are also of interest. For important practical applications of photoemission *see* PHOTOTUBE; TELEVISION CAMERA TUBE.

The salient experimental features of photoemission are the following: (1) there is no detectable time lag between irradiation of an emitter and the ejection of photoelectrons; (2) at a given frequency, the number of photoelectrons ejected per second is proportional to the intensity of the incident radiation; and (3) the photoelectrons have kinetic energies ranging from zero up to a well-defined maximum, which is proportional to the frequency of the incident radiation and independent of the intensity.

Einstein photoelectric law. These characteristics can not be explained by J. C. Maxwell's theory of electromagnetic waves. In 1905 Albert Einstein made the clarifying assumption that the radiation had characteristics like those of particles when it delivered energy to electrons in the emitter. In Einstein's approach, the light beam behaves like a stream of photons, each of energy $h\nu$, where h is Planck's constant and ν is the frequency of the photon (Fig. 1). The energy required to eject an electron from the emitter has a well-defined minimum value φ called the photoelectric threshold energy. When a photon interacts with an electron, the latter absorbs the entire photon energy. *See* PHOTON.

For $h\nu$ values below the threshold, photoelectrons are not ejected. Even though the electrons absorb photon energy, they do not receive enough to surmount the potential barrier at the surface which normally holds the electrons in the solid. (For a discussion of the surface potential barrier *see* SCHOTTKY EFFECT.) The threshold energy φ is associated with a threshold frequency φ/h and

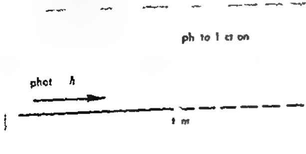


Fig. 1. E... of photoelectric effect.

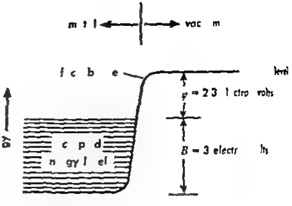


Fig. 2. Energy diagram for electrons in sodium. The photoelectric threshold energy φ in a metal is equal to the electronic work function. The band of energy levels occupied by almost free electrons has a width B.

a threshold wavelength ch/φ, where c is the velocity of light. For photon energies above φ, the kinetic energies of photoelectrons range from zero up to a maximum value $E = h\nu - \varphi$. This is the Einstein photoelectric law, and E is commonly termed the Einstein maximum energy. Careful photoelectric experiments by R. A. Millikan in 1916 fixed h in Einstein's law with considerable precision and furthered its identification with the constant which M. Planck had used in his theory of black body radiation.

Metals. The Einstein law is based only on the photon hypothesis and on the conservation of energy. It does not take into account momentum, which must also be conserved. The incident photon has a momentum $h\nu/c$ which is negligible compared to the change in momentum of the electron when it gains the energy $h\nu$. Thus it is not possible for a free electron to absorb the entire energy of a photon. In order for this to happen, the electron must be bound to another body which takes up the recoil momentum. *See* COMPTON EFFECT.

Figure 2 shows an energy diagram of the electrons in the metal sodium. There is a potential barrier at the surface which the electron must surmount before they can escape. The most easily ejected electrons must acquire 2.3 ev of additional energy from photons in order to do this. This 2.3 ev is the electronic work function, which for a metal is equal to the photoelectric threshold energy. *See* WORK FUNCTION (ELECTRONIC). Inside the metal the electrons occupy a band of energies about 3 ev wide. These electrons are said to be quasi-free. This means that they behave in many ways like a gas of free noninteracting electrons; nevertheless they move in the periodic potential due to the positive ions of the sodium lattice, and in this sense they are bound. *See* FREE-ELECTRON THEORY OF METALS.

In this situation two types of photoemission are theoretically possible: the surface effect and the volume effect. In the surface effect, recoil momentum is communicated to the crystal because the electron is coupled to the barrier at the surface during photon absorption. In the volume effect, the

in the r tal Rather it leads t a k nd of n n nd cti g exc ted t te call d an xciton tate Th exc ton can t ansfer n ugh e e gy to color nte s m eject ph to l ctr ns fr m the cry tal Th two- t p o ess i term d e cit n i duced ph t m i It app ar in the p ak B on the u e i F g 6 It is m re effi ent than d r ct jection of photoel tr n f m c l cent r The enti ry tal is apable f th p mary photo absorpt on and th ene gy can be t a fer ed rather ffici ntly to colo ente s Thu the pr e e a o d m h of th lo s in incide t ergy th t f om th l mited s ect on of olo cen ter he they ab o b ph tons d rectly S Exci TO

Other compounds Oth r oni cry tal h as i m x d h e mu h l k the alkal halide Direct ject on of ph t le tr n f m ch m al imp r t e nd f m rgy le els o d fects local ed at th ry tal rface n be imp nt Be des the e t ns p e ex ex it n nd ed em ion a d nt i s c ph t emi on both e r

Compou ds uch as zi c sulfide beh ve some h t l ke germ n m b t hav h gl ntr n ic th h ld e erg e f the ord of 7 e The photoelect i yi ld a e compa at ely l w s f r g r man um Extr i p e s u h d re t ej c t on f el s f m hem c l imp rit (r defects) a e metim d t table but re u lly eak

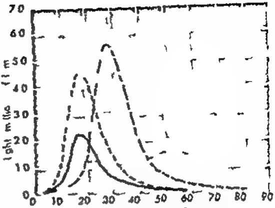
C ta n compl ph t em tters re m de by l t t g e m re t w th il r o d to f rm e i m d nd l e They a luable b e u th y h e th e h ld e ergi b l w l e d thu th y ti e the i fra ed The phot l ct n ppe r t b d e tly y i d the fr m m l o bed n the ide s f ce r from d ete n rgy l l n th i m o d Th yield re b t 10 elect n p i de t ph t n l t n ic emi fr m e m o d (with yield b e 0 01) oc ur f r ph t n rgi s ab e th t t i e thre hold at ab ut 4 e [E A]

B bl og phy W Sh klev (d) *Imp f t s Nea ly P fe t C ystals* 1952 A Somm *Ph t f t i Tube* 2d ed 1951 A Van d r Zi l *S l d St t Phys l El ct i* 1954 V K Zw yk nd E G Ramberg *Ph to l ctricity a d Its Appl at n* 1949

Photoflash lamp

A omb t n lamp that burn with b r t of h gh nt n ty l ght f h t timed r t o d w th d fi tely gul ted tim ch te ti s Th illu t at h w th l m n t m ch cteri t s f me typ l lamp

A ph t fla h l mp h s a gla bulb fill d w th fin ly h edd d l m m f l i an tm ph f xyg n Th f l s ign t d by low ltag d y ll Th ol t mp t s t the r us type a g f m 3800 t 6000 K T p te t g i st b t ng th ut d d i d f the l mp ol ti t ng Ph t fl h l mp s d f tak



lumen-t m urv s f m ph t fla h lamp

ing ord nary photograph unde poor ambi e t l gh t c nd ti n f high peed ph togr ph r quiring fa t hutter speed and l gh inte ty l gh t and f r ph t graphs equiring spec al lighting *Se* PHO-TOGRAPHY [J O K]

Photogrammetry

The pra ti e f bta ning survey by mea of ph tog aphy Phot graph may be tak on the g ound r f om a ai plane S e SURVEYI

Grou d ph tog aph n rmally are taken w th the am a horiz ntal Where p it n ent ti and elev tion of the mera and el atio of obj ect to be m pped ar kn wn m pp ng a b per f rmed with ngle phot graph l y e r ing the pr ed r for on t ucting two-poi t pe pecti e

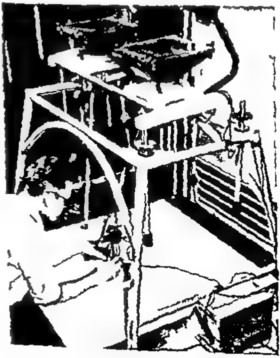


Fig 1 Ster pl tt g t m t (A S rv e C p)

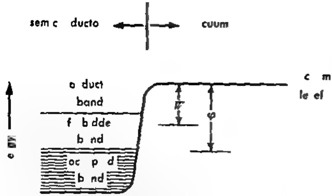


Fig 5 Energy diagram for electrons in a semiconductor The occupied band is filled with bound electrons that behave differently from those in metals As a result the electronic work function W is smaller than the photoelectric threshold energy φ

the semiconductor rises more steeply as a function of frequency than does the yield from the metal A related result is shown in Fig 4 On the average the photoelectrons from a semiconductor emerge with lower energies than do the photoelectrons from a metal of the same electronic work function (or even from a metal with the same threshold energy)

A particularly interesting and important kind of photoemitter is typified by cesium antimonide Cs_3Sb This material is a semiconductor having a forbidden energy band about 1 5 ev wide The photoelectric threshold energy is only slightly higher than this Electrons excited from the occupied energy band by incident photons cannot assume energies lying in the forbidden band They must remain in the conduction band shown in Fig 5 Thus even the slowest ones must retain energies only slightly less than that required for escape The probability of photoemission is higher than for metals (or for semiconductors that have threshold energies greater than twice the width of the forbidden energy band) Cs_3Sb is sensitive over much of the visible range and can give very high yields in excess of 0 2 electron per incident photon It is widely used in practical phototubes Related compounds can be made with enhanced photoelectric response in the red or ultraviolet regions of the spectrum

Alkali halides Three basically different kinds of photoemission are possible for alkali halides—intrinsic extrinsic and exciton induced photoemission

Intrinsic photoemission This is characteristic of the ideally pure and perfect crystal It is thus analogous to the emission already described for metals and semiconductors It appears only for photon energies higher than the intrinsic threshold For example potassium iodide KI is an alkali halide having this intrinsic threshold in the far ultraviolet near 7 ev Apparently the width of the forbidden electron energy band in KI is only about 1 ev less than this For the same reason that was mentioned for the semiconductor Cs_3Sb the photoelectric yields are high in excess of 0 1 electron per incident photon as shown by section C of the curve in Fig 6

Extrinsic photoemission A second kind of emission occurs when a KI crystal contains imperfections in the form of negative ion vacancies (lattice sites from which negative iodine ions are missing) These vacancies can be filled by electrons Color centers which absorb visible light, are formed (see COLOR CENTERS) They may reach concentrations as high as 10 per cm³ External photoelectrons may be ejected directly from these centers by photons It is termed an extrinsic process since the light is absorbed by a crystal defect it is also called direct ionization The threshold energy for this process is about 2 5 ev The yields can reach values of the order of 10⁻ electron per incident photon as shown in section A of the curve in Fig 6 The exact value of the yield depends on the concentration of color centers Most of the incident radiation is lost because it is not intercepted by the centers which present a limited cross section to the incident photons

Exciton induced photoemission When color centers are present another photoelectric process takes place in two stages Potassium iodide has a sharp optical absorption band peaking at a photon energy of 5 6 ev This is the first fundamental or intrinsic optical absorption band Energy absorbed in this peak does not release free electric charges

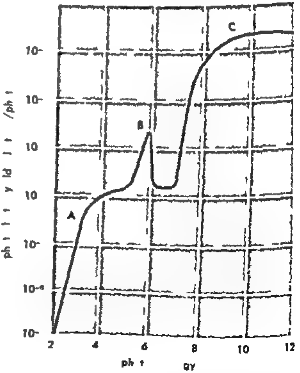


Fig 6 Spectral distribution of photoelectric yield from potassium iodide containing color centers Region A of the curve is due to direct ejection of photoelectrons from color centers; the peak B is due to exciton-induced emission C is due to intrinsic emission

t the mul to c tr l ed image tone con t a t a d f to h rd the gelat n t a t m u f m ty of oat ngs nd t make the emul ion sen t to d ired vele gth

Aft b g ated on the upp rt emulsi n s h ll d t et nd d d to a pecific moi tu e te t Many films a d om late rec e more th t n with d idi l l y be ng as th n a 0 000 n M t x r y film are coated n b th des om bl ck and wh t films a e do ble c at d on one s d d me c l films ha e m re th ix coat n s N e t z d tings may be appl d over th u f c f the em l ion t pr t t a n t ab a n dur ng l dl oll film may ha e a g lat n c ati g o th b k t r d ce the t de y t u l by nte acting the eff ct of the gel t n emul n n th f o t and m t rial f m k g t lly h e an anti halat n at ng n the back Photograph c p p em l n a e ge ally t d thinn r th n film mul n and m e h bly h rd d

Spectral sensitivity The h r h lide e n r m lly en t o ly to the ltr olet) let and bl e b t th y an b m d it e to l ng r wa le gth by dd n t the mul p al dy w ally f th b y n d m ev n n l Thi kn wn a e pt l e t g In d t be able t ep d t al een by the ye mul mu t re p d t w length to h h th ye t tl at pp imat ly 4000– 000 A f l t d

N n e t ed em l on e k own s blu ens ti l bl d rd a y Em l n wh ch ha b t eated with dyes t t nd tl s n t ity th gh the g e n e k wn a rth h m t a d f the en t ty i ext ded thr ugh th d th a e k w p nch m t On o d n ry em l n bl e a p d d l ght d g ns and ed d k O thoch m t m l o epto- d blu a d g l ght nd red as d k d th y a e d st el p tr itu e m m i l d d t i l ph t gr phy and i the g ph rt Pa h m t emul s g re on abl good p du t n i bl k nd hit f th t n h f ol ed bje t d p ti ul ly u f l with nd t l gl t c Th f r th t t f n t b d e t t b nt 13 000 A wh h th n nf d eg o Ul t I t ti ty l m ted by the t ng pt l b pt by g l t b l w 300 A b t m l n sen t t mu h h t w l th are g d n wh h the g l t ha b n edu d t l w m unt

Photographic characteristics M ny f the h t f ti e mat al p fi lly th d c n f tl th f th ph t g phic p es l t nt m d t try d d tl) l (Pho o r t) All th h t l t d t th mb t n of th m l l p d th e p f d d t th t t f th dev l p d m g f g t mj t f d t m n g th q l t f the ph t gr pl d p t l th d fi t th ab l ty t repr d ce fine d tail—tl m t imp rtant fact r l eing grainin re l ing t w r sharp ne nd acutance Grain ne tl ol je t e a perc of g anl lar ty man f t it If a a n nl m gene ous gr i y appe rance whicl may be vi ille h r tly and i alway v ible under magnifi t n High pee l m il n are generally gra ni r tl n slow em l ions th grain ne s l e ng d pen lent t a large xtei t n the natu e of the de el pment and the de ty of the im ge Tl e attempt i c tantly made t i e ea peed with ut obtaining a c r re p nd ngly coar r grain In print tl e gr i i ne is l gl r a th neg ti den ty i rea e

Re ol i g pow r fi rpne s d a uta c d pend n th tu l idity (light catter ng) and inl er e t e ntra t of the em l n R l ing power i es a mea u e of the al l ty to rec rd f ne d ta l and i u ually e p e d a the n mt r f li e per milli meter whi h ca ju t be eparated i ially Re l ing p wer alues n mally r nge up t al t 150 l nes/mm b t may rang fr m le than 50 t r 1000 The al depe d p n th at i f tl e emul the ubject co t a t tl e d n ity and tl e devel per

Sharpne s ref r to th ab lity f th m l n to sh w a ha p line of d m rcat n l t en a ea ec ving differ t e p r U ually t h n edge i n t ha p but g aded t an ext nt d pe d ng upon the d el pme t c nditi n and tl e t rl idity Sha pn s el ted t tl r te f l a ge l den s ty acr s such a b u da y the l je ti e p rt work d ut t describe this in term of numbers i known a cut e

Photographic products Thou and of types and e of plat film and p per a a ail l le for a wid ty of appl cati n Amat ur pr fe i n l mmer ial a d nd t l oduct for am ra e may ra ge from a exp e d f l tha 10 t abo t 1600 fr m ry fine g a nd ptim m ha p s to fa ly c r gr n w th c rre p nd ng lo in d fin tio a d in w der nge f c nt a t d p ctral tt ity espec lly fo sc entific nd ndu tri l ph t graphy Film of extremely h gh ont a t a d d n ty r d i g aph epr du ti w k ndu t y a d i the printi g t ade t g high ont a r l ne d h lf to orig al Blu e it mul a w dely l f r t py ng d m k n dupl ate neg ti Many type f r y film mad s me c at d b th des a d f w th o with t t n fying c

A wide r nge of photogr ph pap r v ilable i clud nt ous t t a d nla g g pa pe n ang of o tra t f p fe al ama t u a d phot fin hi g p i ti g A nge of im ge t and t t d p p pp rt i a a l l l A a ty of p p s k g a r ng l peed a d n t t i a l bl f t a e re d g llo- g ph H gh tr t g t e a d d t p s ti e p p e ed fo phot graph c r pr du ti f d ume t nd ng ng d aw g Pape s f r d cume t p od ct by m g tr n f y t ms a f t f rm (1) l nt l a f in wh h th l l p d n gat v i pl d n nta t with a re

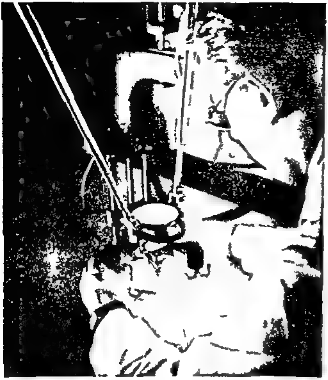


Fig 2 Plotting table (Lockwood Kessler and Bartlett Inc)

drawings Elevations of objects need not be measured where two photographs are taken from known points Positions are plotted from graphic or analytic solutions of line of sight intersection problems

Aerial photographs commonly are taken with the camera center vertical Adjacent photos taken at a prescribed altitude above a reference plane are overlapped The two images of the same terrain then can be viewed stereoscopically that is one image is seen with one eye and the other image is seen superimposed with the other eye

Although analytical methods exist for fixing the points measured on a stereoscopic image direct mechanical solution of the problem is available In one widely used procedure glass positives of the two photos are placed in the projectors of a stereo plotting instrument (Fig 1) With the aid of identifiable position and elevation points (from ground surveys) the photos are oriented to the relative positions they had at the instants of exposure Projections are aimed with the aid of space bars at a plotting table top (white disk Fig 2) which can be raised or lowered The image is in precise focus at the center of the disk only when the disk is at the correct scalar elevation for a given horizontal position The center of the disk is indicated by a small spot of light called the floating dot To trace a contour the operator sets it elevation on a dial integral with the table He moves the table laterally until the elevation focus is centered by the floating dot lowers the plotting pencil and follows the contour by keeping the image in focus at the floating dot With special equipment table movement can be recorded for electronic computer application [R H DO]

Photographic materials

The common sensitive material of photography—plates film and paper They consist of a support of glass plastic sheet or paper respectively coated with an emulsion which in the usual instance is a suspension of silver halide crystals in gelatin and which provides the light sensitive layer in which the picture will be formed

Supports The glass supports for plates are selected for optical clarity and flatness and the thickness increases with the size of the plate ranging usually from about 1/16 to 1/4 in Film support for many years mostly of flammable cellulose nitrate sheet is now almost exclusively of the safety variety consisting of a thin flexible transparent optically uniform sheet of slow burning material—cellulose acetate and cellulose acetate propionate When improved dimensional stability is required film support consists of a variety of polymeric materials such as Vinylite polystyrene polycarbonate and polyesters particularly those related to substances derived from esters of terephthalic acid and ethylene glycol Plasticizers are added to give flexibility in the case of the cellulose ester supports Film support usually ranges from 0 0032-0 009 in in thickness and is made in continuous rolls up to 60 in wide and usually cut to about 2000 ft Photographic paper is made from rag stock or mostly from wood pulp specially prepared to be free of chemical impurities and has high wet strength It is usually coated with a suspension of baryta (barium sulfate) in gelatin to give high reflectance and is calendered if a high gloss is required

Before the emulsion is coated on the support in the case of plates and film a sub or substratum is applied to ensure good adhesion of the gelatin layer (Fig 1) In general no sub is used with paper although it might be needed in special cases such as in water repellent paper

Emulsions The emulsion consists basically of a suspension of silver halide crystals in gelatin prepared by adding a solution of silver nitrate to a solution of halide in gelatin The silver salts used in emulsions are the chlorides bromide and iodides During manufacture chemicals are added

Fig 1 Diagrammatic cross section of film

Fg 1 Sl h ld g ph tog ph m l h ghly m g f d

h l de sy tem but llul nit ate (cell) d n) is d n ph t me ha cal pr du t n and poly nyl t t lbum n nd the r ll d ha be n u ed Gl s ually ed a th pp t whe fl t n and rig d ty req ed Tr nspa nt film upp rt s lly of ll l t t ll l e c l te p pio at p ly ty en pcly t r m te l The o emul i n co t d d of film nd pl t f q tly e th a d d t ng to p ev t b den g f th mag by h l ti n (l ght spr d ng) a g lat t ng t n nte t u l

Th s art fe f t th may b an h of ph to phy w th m jor bhe d g mf a ed ph t g r phy lt a l t ph t g phy high speed pho t aphy t e c photogr phy d um nt p phot ph ph t met y n le part le ec d g m cr ph t gr phy (l d g m rofilm ng) d cu es th th o y of th ph tog ph p oc s l d ng l t nt image f rmat on de el p me t nd ft e nd t at tom t y d k oom q pm t a d ta t nd p j cti p t (enl g) F r el d informatio

AERI L HOTOGR PH ASTRO O IICAI HOTOG RAPHY C ERA CI EM TOGRAPHY L NTE SLIDES LENS OPTICAL MICRORAD OGRAPHY MI CROSCO E O TIC L OSCILLOSCOPE THODE RAY PHOTOEL STICITY PHOTOGRAMMETRY DIOC A PHY SCHLIEREN PHO O R HY SHOCK WA E DIS PLAY SPECTROCRAPHY STROBOSCOPI HOTOC PHY U DERW TER PHOTOC HY

BRANCHES OF PHOTOGRAPHY

Th m i b a hes of phot gr phy m t p f l mme l ed c t l p s i f d i h L nd i m t g phy (mot p tu ph t g aphy)

Am t ur ph tog phy s th bigg t b n h a d n lud mak g pl t g ph f p man nt ec d f m m nt s d f t t pu p es P f s i al photography i concerned primarily with po trait ire for commercial pu po es C mmercial phot graphy s mainly f r ad t ing and i d i t i l ill trati e purp e Educati nal photogra phy s de oted to teachi g and i ual ed ication Pr phot graphy i for n w paper and magazine illu t ati ns of t pical e ent

Photog aphy is one f the m t important tool in cientifi a d technical fi ld It xtend the ange of vi i all w ng r rds to f e ms f f things whi h are in i ibl becau they are a soci ated with radiati n t wl ch the eye i i nsiti e r because they m e t o fa t or are too mall or t o f r away Phot graph are u ed as imple rec o d wh h can b t d ed at lei ur and mea u ed nd fil d for r ference r f r ec i ity

Infrared photography Emul i ns can be made to respond to radiati ns out t a upp r wa elength l mit of about 13 000 A u ing p c al n itizing dye Phot graph can thus b mad of subjects as s ciated with radi t on in the near i frared ich a sp ctra tars h t bje t and subjects which how select t a smi i r effecti n f near in f ared rad ation e pe ially it a m n r differ nt f om i ble radi ti n Infrared ph t gr ph ver l g d t c s f m high altitudes sl ow im p o ed cl rity f detail be a the atm ph re may elect ely t an m t the near nf ared and b ca se th c ntra t f ground obj ct may be high e a a re ult of th r d ff re t reflect ities in the n a nfra d G a s a d f l appear whit bec e hlor phyll s t a pare t to th near in f ar d Inf ar d ph tog aphy has b en u ed in cam uflage d tect n b many g een p nts ab rb i f ed m e trongly th n does the foliage they may match u ally It ha been ed t r ord th d t but o of tempe atu at th su face of h ted obj ts f r ph t g aphy in total d kne (th object b i g illum ated nly by i f ared) in c im log f de phen g alt ed d t oral d docum nt nd th object a d f phot graph ng t xt l s wh re d rk dy int rfe e with v al ex mi at It i us d n medici becau e th ki is omewhat tran p ent to i f a ed a d the b uta u in may be aled nd the r ap p a anc s d n d agn s s There a e many ppl ca t on n b t ny p l ntology nd t h log cal field i cl d ng th g apl ic art S INFRARED RA DIATION

Ultraviolet photography Th is u ed n the pr t g fi ld spe tr graphy d photom cr a phy d by mi e al gi t p l e t g tors nd x m of q sti ned doc ment nd by m um and t ll ti s Th two m thods of ol t ph tog aphy re (1) th flu esc nc m th d n wh h th obj t illum nated by ul tr v let d a filt t d on the m r t b s b th r flect d ult av ol t a d p rm t ly the v flu e ce to r a h the film a d (2) th r fl ted lt olet m thod n wh ch an ltr l t sour e s ed a d the ame i p ded with a filte wh ch pe m t o ly ult iol t t ch the

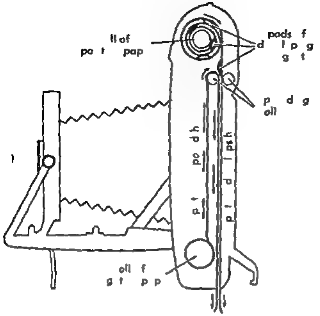


Fig 2 Polaroid Land camera (Polaroid Corporation)

ceiving sheet to which the undeveloped silver halide is transferred by a solvent and is reduced to a positive silver image and (2) the system in which the processed negative is placed in contact with the receiving sheet to which the undeveloped emulsion is physically transferred

Polaroid Land camera photography In this technique the solvent transfer process is used to give direct positive prints in the camera itself The optical system of the camera (Fig 2) is conventional and exposes a negative material in the back (*see* CAMERA) This is wound into contact with a separate roll of paper using pressure rollers which burst a pod containing a thickened developer silver halide solvent mixture which is spread as a thin layer between the two sheets The negative is developed in the exposed sheet and the undeveloped silver halide is dissolved and transferred to the receiving sheet where it is reduced to silver to form a positive image This process is used for obtaining pictures in a minute It is popular for amateur photography and has also been adapted for press commercial and real estate photography aerial photography reproduction of cathode-ray tube images and for other purposes where rapid production of a picture is desired

Storage of materials Films and papers may be damaged by high temperatures and high relative humidities Color films are more seriously affected than black and white because the three emulsion layers may be changed to different extents Protection against high relative humidity is provided by vapor tight packaging which is kept closed until the film is to be used However the package does not provide protection against heat The lower the temperature the better the film keeps and for storage over several months a maximum of 45–55 F is desirable

[W C]

Bibliography *See* PHOTOGRAPHY

Photography

The process of forming visible images directly or indirectly by the action of light or other forms of radiation on sensitive surfaces In the traditional sense photography utilizes the action of light to bring about changes in silver halides which may be invisible necessitating a developer to reveal the image or which may be a directly visible darkening (print out) Most photography is of the first kind and the function of the developer is to convert the exposed silver halide to silver The bright parts of the subject give more exposure than the dark parts so that a negative results that is the brighter parts of the subject correspond to the darker parts of the reproduction A positive in which the relation between light and dark areas corresponds to that of the subject is obtained when a negative is printed onto a sheet of similar material so that the negative tones are reversed In the reversal process direct production of the positive occurs if the developed negative silver is removed chemically and the remaining silver halide is then redeveloped direct positive images can also be obtained directly by using special materials

The common materials of photography consist of an emulsion of finely dispersed silver halide crystals (chloride bromide or iodide depending on the purpose) in gelatin (Fig 1) coated in a thin layer (usually less than ¹⁄₁₀₀ in) on glass flexible transparent film or paper (*see* PHOTOGRAPHIC MATERIALS) The most sensitive materials used for negative making consist of silver bromide containing some silver iodide the slow materials used for prints are usually of silver chloride materials of intermediate sensitivity are of silver bromide or silver bromide and chloride

After exposure of the emulsion coated material in a camera or other exposing device such as a spectrograph or recording instrument the sheet is developed fixed in a solution which dissolves the undeveloped silver halide washed to remove the soluble salts and dried Printing from the negative is done by contact with or optical projection onto an emulsion coated film or paper and the same sequence of steps is followed as for the negative

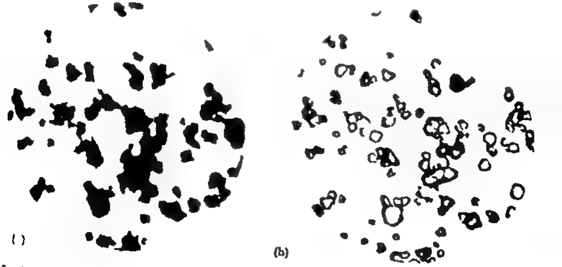
For about 100 years the results of practical photography were almost exclusively in black and white but since the introduction of the Kodachrome process in 1935 a large and increasing percentage of photography has been done in color In color photography development is basically the same as in black and white photography except that the action is accompanied by formation of products which react to give dyes in addition to the silver which is removed (*see* PHOTOGRAPHY COLOR) Other photosensitive systems which are used in photography utilize diazo compounds sensitive iron salts photosensitive polymeric systems dichromated colloids bleachable dyes photosensitive glass and electrostatic electrolytic and photoconductivity effect Gelatin is the common medium for the silver

g th gh r by r fl c pyi g) r in camera and m y be negat e r po t In th c s of negati e c p es (f r xample Ph t tat pri ts) pi al r l i u ed the c m ra to g r ect o entat on In e nta t p int g a l terally re ersed negat i u ually obta ed f m whi h p it e p nts may b mad by pr nting through P t e pi s are obta ed d re tly by u ing spe c I di ect p t e p p r Image tran f r pr c s are s d t g e p it e p t on r ce ng sheet by tra fer f om refl x p ted pap rs (uch s V rifax, Agfa Copy ap d G ae t Ge acopy) Sy t m oth th n l e h l d ystems make opi s by g th rm graphy (Thermofa) n lectro- t t c (graphy Ele trofax) and electr lytic pr cesse *S* PHOTOCOPYING PROCESSES

Photographic photometry The inte s ty f ra d t on the sp ctral d tr b t o of i tensity an b me s red by photogr phy The r di t wh e t t n ty i to b m a u d s ompared with *th t fr m a sta* dard e by m tch ng the photo- gr phi de s t es p od ed by both The m thod i pabl f h gh p ion if th cha a te ti s of ph t gr ph m t r al a e accu ately kn wn and th e ults e t rp eted nt ll tly It s q ite nr h bl t tt mpt to c mpute e rgy f m m a u eme t of a ngle d n ty I pra tic a i e p i m de t th u kn wn rad at on a d a dj c nt es of xp s re (el ely adja c nt the am plate o f lm) mad to th ta d rd u c the p u e n ch tep of the re b ng u tely kn w Th d t n th d el ped plate film fo th t nd rd which m tche that f th nknown s lected a d th nt ty wh ch g e t s als th t wh ch g ve the k ow The nd t o t be fulfilled ar st i t d ha e b e lea ly defin d by L A J nes (1937) and G R Harris (1979) *See* PHOTOM ETRY

Nuclear particle recording Ch rged atomic par ti l s give r c rds on ph t graphic emul i ns and the m thod of re o d ng pro ides an import nt ad j n t t ch detect s as the io izati n chamber the G ger counter a d the Wil n cloud chamber The fir t studi s w r with α-pa t cl which pro- duc a tra k of lver grai s in the devel ped emul on Proto s we e *later found to produce tracks* with grains f d ffer nt spacing Co m c ray gi nucl a disintegrati ns *n coll sion with the atoms* in the em l on starl ke patterns re ult n i ting f r acks made by th *part cles from the at m c* le Tracks of electr ns and other charged par ti les ca be re *rded o special* thick emul i n having h gh l er br m d content sm ll gra n m *m m fog nd appropriate* speed Th grains a e m de de elopable by onizati n within them caused by *imp ct f the particles Se* COSMIC RAYS PARTICLE DETECTOR

Microphotography The p ocess of making pho- t gr phs on a g atl educed scale i call d *mi ro- ph t gr phy* Microfilming is the special techn q e f c py ng doc ment to reduced size on film u u lly 16- a d 35 mm film but 70- and 105 mm width is u ed well heet film The neg ti *es or con ta t p t e films r pap r* prints mad f om th m c n be read in nlargi g reader or *enlargement o to pap r* may be u ed t pr ide copies Special mi iat re m r s are u ed p o ided with m ga zines to h ld 100 ft r mo e of film nd metim s ha ng ariable mag ficat on a t matic *focu ng* nd h gh-d it n lenses Some camer a e in the f rm f desks int wh ch the d cuments ar fed rap dly a d ph tograph d nd m ed thro gh th mach ne utomatic lly Reductio may range f om



( ) (b)

Fig 2 ( ) D l ped f g f ph t g ph m l (b) O g l t fi l d g f m wh h th I ( ) w d l p d b h h ghly m g fi d

film Ordinary orthochromatic and panchromatic films are used according to the purpose and color photography can be done by the fluorescent light method *See* ULTRAVIOLET RADIATION

High speed photography This serves a great variety of purposes in technological studies Modern methods may be grouped as follows

1 Single exposure photography The best mechanical shutters will not permit exposures shorter than about 1/1000 sec although magnetooptical shutters electrooptical shutters called Kerr cells (*see* KERR EFFECT) and electronic shutters have been used for very short exposures Intense light flashes of very short duration are used in shadow photography and stroboscopic photography In other reflected light methods for single exposures a common source is the gaseous discharge lamp used with a normal camera exposure times as short as 1/50 000 sec can be obtained

2 High speed series photographs are taken as motion pictures the normal slow motion cameras with intermittent motion giving up to 128 pictures/sec For higher speeds (up to 5000/sec or more) continuous film movement is used with optical compensation for image movement such as a rotating plane parallel glass block or rings of prisms or lenses Photographs made at these high frequencies when projected at normal projection speeds slow down the motion to the extent of the ratio of the taking and the projection speeds

3 Sequences of short duration photographs can be made at close intervals using flash bulbs gaseous discharge lamps and groups of separate cameras operated in succession Many special high speed cameras giving high taking rates have been devised including the Bell Laboratories ribbon frame camera and the F E Tuttle grid camera

4 When the subject is self luminous of short duration and moving rapidly such as an explosion a rapid sequence of photographs permits study of its development Methods used include short individual exposures through a rapidly rotating shutter onto a stationary or moving film falling in one plane at right angles to the path of the explosion or wrapped about a rotating drum Rapidly rotating mirrors can be used in a moving film camera to give a series of separate photographs or the film may be held still and a single rotating mirror used Continuous trace photographs on moving film have been used to study the initial stages of explosions High speed single x ray pictures have been taken by discharging a high potential of short duration through the x ray tube

Stereoscopic photography This is done to simulate stereoscopic vision (*see* STEREOSCOPY) It presents to the two eyes individually two aspects of the subject made from slightly different viewpoints Relief can be distinguished visually only over moderate distances although the appearance of relief can be introduced in more distant objects by making photographs at greater distances apart Stereoscopic photography can be done by using a single camera and making two separate photographs one after the other from viewpoints separated by the interocular or other appropriate distance by displacing the lens of a single camera for the two exposures or by rotating the object or the camera so as to give a pair of exposures on one film These methods can be used only with relatively stationary subjects Most stereoscopic photography is done by the simultaneous method in which two photographs are made at the same time using two separate cameras a stereoscopic camera (which is essentially two cameras in one body with matched optical systems and coupled focusing movements) or single cameras using beam splitters to give two photographs side by side on the film

In aerial photography the stereoscopic effect is achieved by making successive overlapping photographs along the line of flight in terrestrial photogrammetry photographs are made from each end of a selected base line and in stereoscopic radiography two x ray photographs are made in rapid succession from separate viewpoints

Stereoscopic photographs are viewed in equipment which presents the right eye image to the right eye only and the left eye image to the left eye only This can be done by separate boxes each provided with a lens open type viewers with a pair of shielded lenses sometimes prismatic cabinet viewers with pairs of optics and devices for changing the stereo slides grids or lenticular elements permitting each eye to see only its appropriate field anaglyphs in which two images are printed in ink in complementary colors and viewed through spectacles of similar colors such that each filter extinguishes one image and the vectograph print which consists of a reflecting support on which the stereoscopic pairs are placed one over the other in plastic polarizing layers with the planes of polarization at right angles To view the latter polarizing spectacles are used the eyepieces being arranged so that each eye sees only the appropriate image *See* VECTOGRAPH

Document copying Photography is used for reproducing documents of all kinds because (1) errors are not introduced in the copying process (2) it effectively extends the life of perishable record (3) it offers security against loss and disaster by permitting storage of multiple copies and (4) it can provide for retrieving and disseminating the information in them rapidly

Documents are reproduced to essentially the same size as the original by special copying papers and apparatus and are reduced usually on film in reducing cameras (microfilming) Prints from the film usually 16 35 70 and 102 mm can be made by contact onto silver or diazo-sensitized film sometimes for insertion into window cards or by conventional photographic enlarging or by xerography (an electrostatic process) to give reproduction in any scale

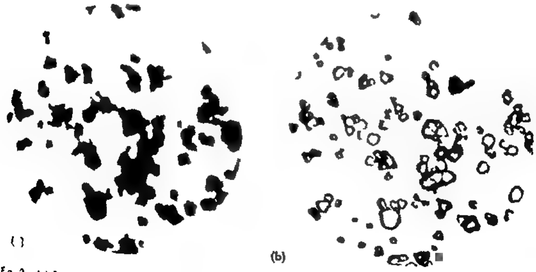
Paper copies of documents at scale or at moderate reduction are made by contact printing (print

ing thr gh or by refle copyı g) or n am ra a d m y be eg t r po tı In the ca e of n gat e op e (fo example Photost t p ı ts) opt c l e r al ıs ed th e m a to gı e or rect re tat I cont ct p ı t ng lat r lly re r ed neg t m u ally hta ed from which tı e pr nts may be m de by pr nt n th ough P t e opı are obta n d dı e tly by using spe al dı ct po ıt p pe s Imag tr sf r p o s es ar d t gı e p ıtı e prı t on r ceiving heet by t nsfer fr m eflex prı ted p pers (su h a Ve fa Agfa C py ap d Gevaert Ce copy) Sy tems othe than s l er hal de y tem mak op es by us ng th rm graphy (Th rm fax) r lectro t t (xe graphy El tr fax) a d electrolyt c p e se S e PHOTOCOPYING PROCESSES

Photographic photometry The ınte s ty of ra d at n r the p ctral d tr b t o of ı te s ty c n be me r d by photography The rad at n wh e ı t n ty to b mea u d ı c mpa ed with th t f om a sta d rd ou ce by match g the ph to graph d tı p od e d by both Th meth d ı ap bl f h gh pr ı n f the ha ct ı t s of phot graphı mate ıal a ac urately known and the r lts a ınte preted ıntelligen ly It ıs quite u l bl to ttempt t comp te en rgy f om me u eme t of a gl de ıty I p a tı c ın gl xp u e m de to th kn w r dı t n a d a dja t e s of e po re (l ely adj c t th s me plat or film) s m d to th ta d d so r the expos e ı ach tep f the b ng a u at ly k wn Th d n ty th d l ped pl t film to the tanda d wh h matches th t of the k wn s elect d a d th t s ty whı h ga e ıt ı) th t whı h g ve the unk own The nd t s t be fulfilled ı t and h h en clea ly d fı d by L A J ne (1937) and G R Harrı on (1979) S e PHOTOMETRY

Nuclear particle recording Charged tomic par tı l s give records n ph t graphıc emul ı n an l the method of reco dıng p ov de an ımp rtant ad junct to such d te t rs as the ı nization chaml r the G ıg r c nter a d the Wıl on cloud chamber The f rst studies w r with α-particle which pro duce track of s l er gra ns n the de eloped emul sı n I r t ns were later found to pr duce tracks with grains f different spacıng C m c rays give nuclear dı ıntegrat ns on c llıs on with the atoms ın the em l ı n starl ke patterns re ult consı tıng of tr cks made by the partı le from the atomic nucl ı T ack of lectr n and ıl r cl rg d par t cles can be record d on pecial thick emul ıon ha ıng l gh sıl er br mide content small grain minimum f g and appropri te peed The grains a e made de elopable by ı n zations wıth n them au ed by ımpact of the particl s See COSMIC RAYS PARTICLE DETECTOR

Microphotography The proce f making pho t g aphs o greatly reduced cale ıs called micro phot graphy Microfilming ıs the pecial techn q of opy ng d ument to red ced s ze on film usu all 16- nd 35-mm film but 0- and 107 mm widtl ıs u ed a well as sheet film The negatives or on ta t po ıt e films or p per print made f m them c n be re d ın enl rg g re der or enlarg ments nto p pe m y be ed t pr ıde copıe Special mı ı tu e cameras re u ed p ıded with maga zınes to hold 100 ft or more of film and ometım s ha ı g ar able m gnıfı at on ut mat c focusing and l gh def ıtı n len Some cameras a e ın the f rm of de ks ınto wh ch the d cume ts are fed rap dly a d phot g phed and m ed through the mach ne automatı ally Redu tı ns may range fr m



( ) (b)

Fig 2 ( ) D l p d l g n f ph t g ph
l (b) D g l l h l d g f m wh h
th T ( ) w d l p d S h h ghly m g f d

8 to 40 but in extreme cases by using lenses and films of exceptional definition as in the Minicard system a reduction of 60 time has been used Special projection equipment made for reading the films may give an enlargement onto a table or a diffusing rear projection screen with provision for rapidly winding the film and framing any desired page

THEORY OF THE PHOTOGRAPHIC PROCESS

The normal photographic image consists of a large number of small grains of silver They are the end product of exposure and development from the original silver halide crystals of the emul ion which range up to a few microns in ize (see Fig 2) The size and distribution of size of the crystals are determined by the way the emulsions are made the sizes are closely related to the photographic properties In general the high speed negative type emulsions of moderate contrast have crystals which cover a wide range of sizes whereas the emulsions with low speed and high contrast have crystals which are small and fairly uniform in size

When an emulsion is exposed to light an invisible change called the latent image is produced The effect of exposure is made visible by de elopment in a chemical reducing solution which converts to silver the crystals unaffected by the exposure leaving unreduced those not affected The darkening (density) is determined by the amount of exposure and the extent of development and depends on the number of silver grains developed in a particular area

With very high exposures density may form directly without de elopment as a result of direct photolysis of the silver halide giving silver This is known as the print out effect Its use is confined mostly to making proof prints in portraiture and in certain direct trace recording in truments

Development of exposed crystals starts at isolated points on the surface These appear to be associated with points having special sensitivity indicating that the latent image is concentrated at specific points These so called ensitivity centers appear to be as ociated with specks of silver and silver sulfide in the crystal surface

Latent image The term latent image refers to the change occurring in the individual crystals of photographic emulsions whereby they become de velopable on exposure to light Once de elopment has been initiated it continues in an indi idual grain until effecti ely all the silver halide is con verted to silver

The concentration speck theory of S E Sheppard A P H Trivelli and R P Lo eland forms the basis for latent image theory and suggests that the light energy absorbed by the crystal is concentrated in the vicinity of the sil er sil er ulfide pecks where it liberates sil er from the silver halide Most evidence indicates that the latent image is mostly sil er and that the sil er speck can initiate de el pment of the crystal when it has grown to a certain size The present theory of the mechanism of latent image formation ugge ts that on exposure the electrical conductivity of il er bromide is increased by electrons becoming available J H Webb suggested that the electron could move freely through the crystal and become trapped at the sensitivity specks In addition there is conductivity of the silver bromide caused by movement of silver ions R W Gurney and N F Mott visualized a combination of the e two processes to explain the formation of the latent image as follows

On exposure the first reaction involves liberation of electrons when energy is absorbed by the cry tal These electrons are able to move freely in the crystal until they impinge on the sensitivity specks where they are trapped and build up a negati e charge This charge attracts the positively charged free silver ions which wander to the specks where they are neutralized by the electrons to give neutral ilver atom as a result of which the specks grow until they are big enough to act as development nuclei The Gurney Mott theory is not entirely adequate but together with the concentration peck theory it is the best ba is for the explanation of latent image formation at the present time For additional information on the Gurney Mott theory *see* PHOTOLYSIS (PHOTOCHEMISTRY) *See also* PHOTOCONDUCTIVITY

Latent images are formed not only on surfaces of the crystals but also in their interiors In the latter case the latent image is presumably associated with localized structural imperfections in the crystals The internal latent image is frequently formed by very high intensity exposures of short duration

Development De elopment is of two kinds physical and chemical Both physical and chemical developers contain chemical reducing agents but a physical developer also contains silver compounds in s lution (directly added or derived from the sil er halide by a solvent in the developer) and works by depositing sil er on the latent image Physical development as such is l ttle u ed although it often plays some part in chemical development A chemical de el per contains no sil er and is basically a source of reducing agents which will di tinguish between exposed and unexpo ed sil er halide and convert the exposed halide to il ver Developers in general use are compounded from organic r ducing c mpounds an alkali to gi e desired acti ity od um sulfite which acts as a pre servati e and pota sium l rom de or other com p unds used as antifoggant (fog is the term used to indicate the d elopment of t nexposed crystal it is u ually desirable to suppre f g)

Mo t de elopi g agent used n n mal practice are phenols or amine and a cla ical rule which still applie although n t exclu ly tate that developers must contain at l a t two hydroxyl gr ups or two amin group or one hydroxyl and one amino group attached orth or para to each other on a benzene nucleu Some de el ping agents do not f llow th is rule but am ng the co

mo develop wh ch do are hydr qu none monomethylparamino-phe ol (El n M t l) pyrog llol (1,2,3-hydr xybenzene) Am d l (2,4-d amin phe nol) a d p-ph nyl n d am ne I 1951 Ilf d Ltd pr du ed Ph n d (1 ph nyl 3-pyrazol don) which ca epla a gr at pa t of M tol in m ny m tol hyd oquin n dev l pers Metol and hyd oqui a e f equently u ed together

Alkalies g n ally u d r d um arb nate sod um hydr de and s dium met b ate (Kod lk) Sulfite i de elope act by lowering the t d n y f r x dati n by the Oxidati n prod ets of de l pers ha n unde irabl influenc on th o r e f d elopment nd m y result in tain l pi g age t nd formulas a e s lected f r u e with p ifi mul on a d p rpo es M de n lo phot g aphy el es ma ly n p raphenylene-d am ne der t ve So-c ll d fin gra n de lop e s a m d t edu e th appa ent grainin of negati s Th y ge e ally cont th con ent o al comp nent but e dju ted t low acti ty and o t a s l e t f r sil mid O f ne-gr n de loper b ed n pa aphenyl n d m n wh ch it lf s l e h l de ol e t Some developers r c mp unded f ha de ng the g l tin wh r dev l pment oc u the unh rde ed a as b ng w hed t t g r l ef im ges for photomechan al repr d ct n nd imb b ti n lor pri t g In c rt m t ri ls uch a the fax m t m te al the h rden ng d elop ng gent ncl ded n the em l i n devel pm nt b g ini ti t d by apply ng a alkal called an ct ator F r peci l purpose m ob ths n i t n of a dev l p ont g fixing ge t ha be n u ed

When a e po ed film is d l p d th u lly a pe i d du which n v s ble effect p pe s ite thi th d n ty n r a es ap dly t fir t d th m lowly e tu lly r ch g m m l th mpl t c e the l t b tween d s ty nd dev l pme t t me s

$$D = D\ (1 - \ \ )$$

whi h D s th de ty att ned time t D s th m x mum de elop bl de s ty nd k i n t nt alled the el c ty on t nt of dev l pme t

After processes Th n l d fix ng washi g d y ng r du t a d t n ifi at n d t g

F xi Aft th mage s de l p d the un ch nged h l de r m d ually wate l t f d m amm m th lfat (k own r peri ely a hypo nd *amm* m hypo) Th r m al f n ha ged h l de s c ll d fi g P i fi g a d l t a d t p h th ften u ed t ut l th lk l c d f om the dev l pe Alt r t ly d fi g bath nta n ng th lfat lfit a d ac ti a d mmo ly used a d h d e s m y be add d t pr v t soft f th gelat Th ate f fix ng dep ds l g ly n the e e t at n of th fi g agent nd th t mpe t l th f sod m th o lfate th rate f fi g i m t ap d at 0–40°C e n n t t d t i mpe tu e f 60–75 F

Washing Negati es and pr nt are wa hed in water aft r fix ng to r mo e the oluble l er halide- ng agent complexe wh ch might render the photog aphs unstabl on keeping or might cau e n The rate f remo al of the comp und l y washing is exponenti l and incr ed by rai ing th tempe ature and increa ing th agitation The rate can be ac elerated by e itral alt lit n know a hypo clearing aids thu red c ng the wa h ng time Remaining trace of thio lfate m y be r moved by chemical treatment wl ich on erts the thi sulfate t sulfate that does n t affect the mage on storage

D y ng After wash ng the materials mu t be d ied preferably n moving wa m air In the of pape pr nts dry is freq ently d ne on h ated metal dr ms which mav al o g ve gl s t the print f they re dried with th ir emi l ide to th metal urface

Redu ti n and i tens ficati n Redu ti n r f r to method f decrea ing the den ity of image l y hem cally d l ing part of the l er l y u ng o idizers Acco di g to the mpo ti n xidizer may remo e q al am unts of sil er from all d n i t e r remo e sil er i proporti n to the amou t present r rem more il f om the higher d ns t es tl f om the lower

Inten ification fers t m th ds f r ncrea g the d n ity of an mage u ually l y dep it n of il er me cury r th r comp und the mp ti n be ng el cted acc rd ng to the nat re f the inten ifi ati n required

To ing Photog aphs re no m lly d d to b r s nably ne iral in c lo By sp cial treatment known s t n ng the l can be modified f r in t nce by add tions to the devel p r by the s l ction of pe ial de lope by to i l t o hich c vert the s l er mage nt uch ompounds s l e sulfide or by pre pitati g col red met l l c salts w th th l m g Dye mag ar obtained by methods f c lor de el pm nt

SENSITOMETRY

St ictly peaki g en t metry refers to th m asu m nt of ens t ity f ph t raph m t ri l b t in pract t i el des a va iety f other fact wh ch d term e th prop t es of th fin l mage The mplest method of det rmini g ensi ti ity i to g e a g aded es of xp su es a d lect th e p u e qu d to g ve the l w t s ble den ty M de n sitom t y d pe d on plott ng curves sh wi g the rel t o between exp s e F nd th den ity of the s l er im ge la t on th der l pment p tral q l ty f the l ght u ce a d the f to s ty D defi ed s the l ga thm f th pa ity O wl h i in t n d fi ed as the recipr cal f th tr spare y T If l ght f nt ty I f ll neg t and i t ity I t nsmitt d

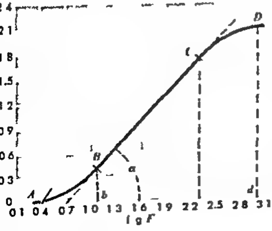
$$T = I\ \ I \quad O = 1/T = I/I \quad D = l\ \ I/I$$

Th elat n hip b tw n d n ty and the l ga thm of exp u e i shown by the Hurte

Driffield characteristic curve which has three fairly well defined proportions the greater part of which in most cases approximates the straight line B to C in Fig 3 In thi region the exposures are directly proportional to the brightness values in the subject In the lower and upper portions of the curve this proportionality does not apply these portions are known respectively as the underexpo sure region (A–B) and the overexposure reion (C–D)

The characteristic curve is u ed to determine the sensitivity or speed of a material the con trast the exposure latitude and the tone reproduc tion It is obtained under controlled conditions using a light source of known intensity and spec tral characteristics a modulator which gives a se ries of graded exposures of known values develop ment under precise conditions and an accurate means of measuring the densities

The internationally adopted light source is a tungsten filament electric lamp operated at a color temperature of 2360 K (that is 2360 K is the temperature of a black body whose radiation has the ame energy distribution as that from the tung ten surface) combined with a filter to give spectral quality approximating that of mean noon sunlight in Washington D C namely 5400 K (The color temperature of the sun as filtered by the atmosphere when the sun is on the meridian at the latitude of Wa hington D C is 5400 K see COLOR TEMPERATURE HEAT RADIATION) The light source and exposure modulator are combined in a sen itometer which gives a series of exposures in creasing stepwi e or in a continuous manner Sen sitometers are either intensity cale or time scale in truments depending on whether the steps of ex posure are made at a con tant time and varying in tensity or at constant intensity and varying time The exposure may also be intermittent that is a eries of short times adding up to the de ired total time Continuous exposures are preferred to avoid the intermittency effect (Below certain critical high frequencies the photographic material does not add up separate short exposures arithmeti cally) The best ensitometers are of the continu



Fg 3 Ch ct tc c rve

ous exposure intensity cale variety and the expo sure time used should approximate that whi h would be given the material in practice

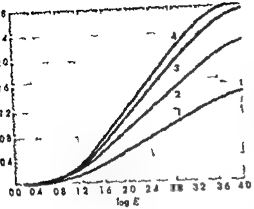
Development is carried out in a pecified f r mula or in the developer recommended for u e with the material under te t for the desired time or se ries of times at a standard temperature of 68 or 75 F and with agitation which will en ure uniform development and reproducibility

Densitometers Photographic den ity i mea ured in a densitometer Early den itometers were based on photometer The principle f the in erse square law was utilized in many in trument (that is the intensity was determined by the di tance of the lamp from the photometer head) and in others the intensity was controlled by polarizing de ices Usually two beams are taken from a tandard li ht source and brought together in a photometer head one beam pas ing through the den ity to be mea ured and the other through a device for modulating the inten ity so that the two field can be matched Visual instruments are still used but largely a primary reference standards Most den itometer are photoelectric the intensity modulating device usually being a standard density which has been calibrated on another instrument or variable aper tures

The simplest photoelectric tran mission den sitometers are of the deflection type con i ting of a light source a barrier layer cell and a microam meter the density being obtained from the relati e meter deflections with and without the ample in place Other photographic den itometer emplo the null system in which the current re ulting from the tran mis ion of the te t ample is l alanced by an equivalent current deri ed from another pho tocell or from the ame cell illuminated by the light beam through a calibrated modulator in alterna tion with the light beam from the ample The trend in practice is to u e another null method in which the mod ılator i placed in the ame l eam a the te t ample and o ontr lled that the total transmittance of the ample and the m dulator i kept con tant by balancing again t a c n tant com pari on beam Many den it meter are equipped with de ice for a tomatically pl tting tl e charac teri tic c irve The den itometry of col red images pre nt pe ial problems a d reference l uld be made to tl e p l licat n of C E K Mee and R M E an W T Ha on Jr and W L Bre er li ted in tl e bil li gr phy

When light pa es tl r gh a neg ti e me i pecularly tran mitted and me i attered If all the tran m tted l ght i i d in l n it metry the re ult i called tl e diff l n ty If only tl e light pa ing directly th igl i m a r d tl e den it i called pecular The l ffu s l ity i l igl er and is related to p cular d n ty l y a r latı n h p known a Callier Q f ct r

In tl ca f paper p rint tl l ty i mea ured l r flecti n Tl e r fl tion d n t i D_R = l g ($1/R$) wl er R i tl r t f light l t l l y tl e paper t tl at f tl e im g on it



Fg 4 Ch ct t urv f d l pme t t m s g th d 1 2 3 4 b ol f t m t dl d

If the t aight l e of th cha act r t c curve BC xt d d to m et the e p r a s at (all d the i rt a) on Fig 3 the angle α i us d t pre t t

Th tangent f α that i th lope f th l n BC known a γ A th tim of d vel pment n cr s the l p f the curv i a es e nt lly reaching a m x mum (F gs 4 d) Th pr j e t f the t ht l ne BC f Fig 3 o n the epo re axi t be t the l t t d and th d tan e d r pr e t th t tal le th t is th wh le po u e rang i wh ch b i htn ss d ffe n a n the ubj t be pr ented

Speed Tl t ty o peed of a mat al s d i ed fr m th l racteris ti r e Th e rli r Hurt nd Driffi ld peeds w re bta ed by di d ng 34 by the xpo r r p nd g t th in ert a S me m thod (Eder He l t S h ne) we ba d th exp s n q i ed to g j t p r pt l l de ty B t sh a d Am r tand d p d e based o the xp ure E th t e of th rs whe e th gr d i s 0 3 f th a erag grad nt C r ng f 1 5 n th l g thm f e p (F g 6) The peed 1/E In der ng p u e d es and t ng f e with xp m ter lety fa tor was ppl d The Ge m n DIN p e l e ba d on the xp s e e p nd ng t d ty f 0 1 i th toe f th rs The fixed de ty t r l t s w ll with the l t al g ad t p d wh n d l pm nt t ll d t g a f ed t g g d t

Cl ra t t f p t pape der r m ed th ame gen al l n a g t m t al m t nt f ct be g e p u e cale d n l al d ef l max mum de ty nd p d th latt r b g b d n gr de t t the h ulde l th rs

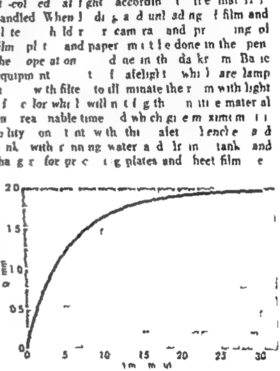
Tl d n t lt g f m a exp s re i ll t l p ndent l th ab lut l of t n t a d t m an eff t kn wn fa lur of the re p t l

Tone reproduction Th ef t the r latt n bet en th l m e d l m an e d ff r n s n th l ject nd th d n ty l d n ity d ff r nces in th pl t graph It ha ol je tive and b- je t ve a pect a d ha been th oughly wo ked out

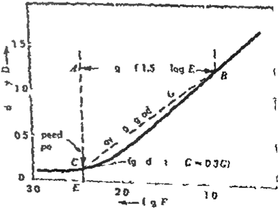
PHOTOGRAPHIC APPARATUS

Tl am a is the ba c in tri ment f ph tog r phy and d ed eparat ly [e CAMERA) A gr at ari ty of a i ili ry am m app rat i i u ed Oth r important appa atu of ph t g aphy incl d s tl e m an f r l ght n tl i l je t quip m t f pri t by ontact r proje t n a d for iew n t an parencie d ic f handl ng film plates nd paper i the ari s tage f p ce m a d mean f viewing t r ng and retri ing pl ot graph

Darkroom equipment Tl e lark m ma ange fr m t tal da kne t roo i light wil nte med at -col ed af l ght accordin t tl e mat ri l handled When l di g a d unl ad ng f film and pl te h ld r r cam ra and pr ing of film pl t and paper m t t e done in the pen the ope at on d ne in th da kr m Ba ic equipm nt t f afelight whi l are lamp h w th filte to ill minate the r m with light f c lor whi l will n t f g th n iti e mater al n rea nable time d wh ch gi e m ximum i bility on t nt w th the afet l enc e a d nk with r nn ng water a d dr in tank and ha g r for pr c i g plates and heet film e



Fg 5 G mm t m f d l pm t



Fg 6 Sh w g d t n of f ct l g d t p d

tically tanks for roll films which are usually cylin drical and light tight and contain a reel onto which the film is wound in a spiral with spaced convolu tions to permit access of the solutions spiral reels onto which film can be wound for processing in a tank or tray flat trays for sheet film plates and paper sheets and occasionally short roll films thermometers for determining temperatures of o lutions or mixing valves to give water of desired temperature for controlling olutions in tanks special multiple tank units for color photography tanks trays or special wa hers for washing nega tives and prints dryers ranging from simple clips for hanging negatives in the open air to cabinets having forced warm air special dryers for prints including simple blotting paper sheets and heated flat drum or belt dryers including some which fer rotype (that is gloss) the prints by drying them in contact with a polished surface clocks and preset timers printers and enlargers print trimmers and for specialized work densitometers printing exposure meters and focusing devices

For professional pro essing of negatives and printing and processing of prints on a large scale *(for example in the photofini hing industry)* con tinuous film and roll paper pro essing machines and automatic or semiautomatic printers for contact printing or enlarging onto sheets or roll of paper are used Continuous machines are made for proc essing x ray negati es in sheet form on a large scale and many continuous processing machines have been designed for special purposes such as aerial photography microfilming scientific record ing and motion picture film

Contact and projection printers Negatives pro vide the primary records of photography in the black and white field and to an increasing extent in color and in many cases such as the document reproduction field they may be more u eful than the positives In general however po itive prints are required and such prints are made from nega tives in contact printers and projection printers (or enlargers)

Contact printers These are boxes containing lamp a glass top on which a negative i placed over which and in contact with which is put a heet of printing paper and a lid or platen which is pro vided with prings air bellows felt spongy mate rial or other means of applying uniform pressure to pre s the negati e and paper into good contact Vacuum or air pre sure may al o be u ed to provide contact Contact printers print on single heets or roll of paper fr m single negatives or rolls of neg ati s Expo ure timers and photoelectric cells for automatically controlling the expo ure may be in corporated Po itive film tran parencies may be printed from negative particularly lantern lides and moti n picture film in long roll

Reflex printing i done by contact by expo ing through the ba e ide of the phot graph c paper the en iti e ide of which is in contact with the origi al d c iment In bireflex printing the ex posure is also made through the en itized paper but its base side is in contact with the document, the base being translucent In contact printers for thermographic proce ses the reflex principle i used the source of radiation in the printer being mainly heat

Projection printers (enlargers) These are opti cal projectors consisting of a lamp hou e and li ht ource a holder for a negative a conden er or d f fusing sheet a projection lens designed to give op timum quality at relatively low magnifications means for focusing for the desired ma nificati n, sometimes automatically coupled to en ure good focus at all magnifications (autofocus enlarger) a support for the optical components and a board or ea el to carry the sensitive paper Timer man ually or photocell operated may be incorporated to control exposure time Projection printer may expo e individual paper sheets or roll of paper from single negative or rolls of negatives

In some printers (for example LogEtronic print ers) the negative is scanned by a pot of li ht which at the same time exposes the printing paper the exposure at any point being controlled by the *re pon e of a photo cell to the cannin beam*

[W C]

Biblio raphy H Baines *The Science of Photography* 1958 T T Baker *Photographic Emul sion Technique* 2d ed 1948 W Clark *Photogra phy by Infrared* 3d ed 1959 G T Eaton *Photo Chemistry in Black and White and Color Photogra phy* 1957 R M Evans W T Han n Jr and W L Brewer *Principles of Color Photography* 1953 P Glafkide *Photographic Chemistry* vol 1 1958 K Henney and B Dudley (eds) *Handbook of Photography* 1939 R W G Hunt *The Repro duction of Colou* 1957 T H James and C C Higgins *Fundamentals of Photographic Theory* 1948 G A Jone *High Speed Photography Its P inciples and Applications* 1952 A W Judge *Ste oscopic Ph tography 3d ed* 1950 R Kings lake *L ns s in Photography* 1951 A Kra zna Krau z (ed) *Ph tog aphy Theory and Practice* 3d ed 1954 C E K Mees *The Theory of the Photographic Process* re ed 1954 W D Mor gan (ed) *The Complete Photographe* 10 vol 55 pt 1941 1943 C B Nel lette *Photography Its Materials and Processes* 5th ed 1952 S E Sl eppard and C E K Mees *Investigations on the Theo y of the Ph tographic Proc ss* 1907 D A Spencer (ed) *P og s in Photog aphy* 3 vols 1940 1958 G W W Ste en *Microphotography* 1957

Photography color

A large pr p rti n of phot graphy i d ne in col r The camera exp u e may re ult in l la k and white eparation negati es a po it ol r tran parency or a negati e c l r tran par ncy print n film r paper or th r white support may be made from the e by a variety of color print ng pr *See* PHOTOGRAPHIC MATERIALS PHOTOGRAPHY

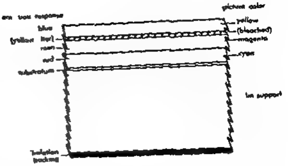
The tw practi l proce e of c l r ph togra phy ar the add ti e and subtr cti e systems Since 1935 the subtr cti p oc s ha bee u d al m t xclu v ly The fir t step in both ca e is t make ph tog aph of th subject by t blue g een and ed omponents (hence the xp ess on th ee- c l r ph tography) d d ng the spectrum i to thr e r ughly equal parts by m an f l ght filter r c l r filters Two- lor proc s es ar u ed t a limited te t di idi g th color int two c mpo e t blu g en d o ange b t th res lts t olo e deri g gre tly nf ri t th t of the th ee- olor method

Additive processes I the the olors ar p o- du ed by dd ng bl g een a d d in the am unts p e e t the r g n l bject Th re re thr m ystems tr ple p jecti n or w ng the screen u it sy tem nd the lent ular film p oc e s In th fir t three negati es a e mad in suc c n a singl am ra s m ll neo sly in a one sh t am r or a tripa k u l hro- m t c film (film it ve t l ght f all colo) and bl k nd whit p t tr n pa e c e m d f m these are p j cted or v ewed dire tly n u pe po ti n ea h po t e b g illum ated by the f l r by which it neg t e s made Thus in th d s l ttl u ed although ts p i ple i empl yed in de e kn wn the Cu t an lyzer to c nt ol ph t m hanical ep d t o color

I th se e unt p es iyp f d by th L m e e Auto hr m plate nd D faycol r film the plat r film s d w th a lay f mi ut bl e g e n d ed el me ts ove wh ch a pa ch o- mati emul o s t d Exposur th ough th e f red leme t (s reen un ts) d dev l pment by the rever al p s gi es a p tiv bl ck a d h te imag b ken up i t l m ts c rre pond ng t th ecr n u ts d of d s ty d terms d by th ol of the origi al D t ewing of th omb n t o gi es lo rep od ct n

The f t l r film pro (Berth Kelle D E tm K d k ea ly Koda lo proc) e a film mb d on the b ck w th m n t le wh h n th m ra f e th len wi h arrie th ee- l r ba ded filt D lopm t by e e l nd th phot graph s b ke up t m n t leme t ea h f wh h n image f the filt a d ol d n t rr po d ng t the lo f th bj t at th t po r P j ct n th ugh m l ba d d f lt gi es ol r p d ti n Th l nt ula s t m h s be d f mon to g l r t l i n

Subtractive processes In the techn q es a in th dd ti e p es e th ubject s ph t gr phed by blu g and ed l ght but from th n g ti s po it are m de i dyes pig m t l mpl me t ry t th by wh h th po d ng n gati e were made, n th s e e respect ly y ll w mag t a d cy a d th three c lored po t es e i e ed i s ip po i t o tra p r nt film wh te p pe The th ee sepa ati n g t e made i th me w ys



C o ct o of Kod ch m film

mention d f r add ti e proce ses or as monopacks or i tegral tripacks in wh ch they are not sepa rat d f r use but converted directly into m lti layer color ph togr ph

The mon packs pro de the bas s for most color phot graphy E ent ally *they cons st of three* emul ons oated one ab e another and ens tive e pecti ely to blue *green* and *red* l ght, the blue- sen iti e layer be ng n top with a yellow filter layer between it and the green ens tive layer to pre ent penetrati n f blue l ght to the l wer lay ers The thre olor im ges i *the sepa ate l ye s* a e f rmed by using de elopers which gi e ox da t on produ ts wh ch comb ne (ouple) with dye- f rm g comp nents (couplers) p e ent in the de elop r *r in the emuls on* the co pl rs be ng s lect d to g ve a y ll w dye in th blue en itive l ye a m gent dy th green and a cyan dye i th red

In Kodachr me film the fir t s cce- ful m no- pack (1935) sed fo m ki g color tran parencies n film the xp ed film is dev loped t give a *bl ck a d wh te* n gati e n ea h laye It is th n xp s d thro gh the b se to red l ght which ex pos th und eloped l e l al de in the ed sen iti e bott m laye developme t in dev l pe *conta n* ng a cyan oupler gives a cyan po ti e image Expo e to bl e light *from the* f nt and dev lopm nt with a yell w c pler p e ent gi e a y llow dye p iti in th top laye The m ddle l y the m de de elop ble to gi e a mage dye imag tfe il er all th e layer s bl ached ut and a three col transpa e y rema s (see llustr t n)

In the th m pack method f m king posi ti e col r tr n pare c es th dye f rm g co iple s e nco p r t d in the em ls o s th s perm tting s m lt n u *pr d t* i f th th e dy images n a s gle d el pment tep In f rm (Agfa l A c l r films) the c plers a e ttach d to hea y m lec le whi h pr ent them f m d f fus g o th t each dye i form d i t app o- priat l y In th th f rm (Ekt h om film) the co ple s a e mad tat o ary by d sol g th m n tly l quid wh h a e fin ly d pe d n the em l ons In b th pr es t bt n p s t c l r t n pa n a fi t de elopment g v black and white neg t ves n all th e l y col r dev l pme t giv l po iti es f m the es d al

silver halide in the layers and bleaching the silver from all layers leaves a color transparency

Negative color films (Kodacolor Ektacolor Agfacolor Negative Gevacolor) are obtained from monopacks similar to those described but developed directly in a color developer followed by bleaching the silver the result being a color transparency in complementary colors In the case of Kodacolor and Ektacolor negative films the couplers used are actually colored red and yellow (apart from the developed color) and these colors are destroyed in proportion to the amount of dye image developed so that the negative dye image is associated with a positive image in red and yellow This colored mask offsets lack of purity of the negative dyes and gives prints of improved color

Color printing processes All satisfactory color printing processes on paper or other reflecting support are subtractive The pictures are formed by combining three positive dye or pigment images in yellow magenta and cyan Chemical toning dye mordanting pigmented bichromated gelatin or silver halide gelatin and dye bleaching processes have been used commercially The imbibition process (Kodak Dye Transfer) is used for professional prints three gelatin relief images (matrices) being made from the separation negatives dyed in their respective color and the dyes transferred in succession by contact to gelatin coated paper

Most color prints are made by coupler development using the monopack type materials described for films but on paper or white pigmented cellulose acetate support They may be made by reversal processing to give prints from positive transparencies or by the negative positive process to give prints from color negatives following essentially the techniques used with incorporated coupler films

Color motion pictures Additive processes have been used for color motion pictures one of which the lenticular process provided the first amateur 16 mm motion pictures

Practically all color motion pictures are made by the subtractive process although chemical toning and dye toning were used earlier to some extent to give the colored images from color separation negatives The Technicolor process uses dye imbibition the separation negative being made in a beam splitting camera more modern processes use monopack films giving direct positives which may be printed onto a similar type of film to give duplicate positive or direct positives from which separation negatives are made for printing by dye imbibition or in most cases color negatives printed onto color print film all using the incorporated coupler system *See* COLOR FILTER COLOR

[W C]

Bibliography G T Eaton *Photo Chemistry in Black and White and Color Photography* 1957 R M Evans W T Hanson Jr and W L Brewer *Principles of Color Photography* 1953 R W G Hunt *The Reproduction of Colour* 1957 *see also* PHOTOGRAPHY

Photoluminescence

A luminescence excited in a body by some form of *electromagnetic radiation incident on the body* The term photoluminescence is generally limited to cases where the incident radiation is in the ultraviolet visible or infrared regions of the electromagnetic spectrum luminescence excited by x rays or γ rays are generally characterized by special name The graph of luminous efficiency per unit energy of the exciting light absorbed versus the frequency of the exciting light is called the excitation spectrum The excitation spectrum is determined by the absorption spectrum of the luminescent body which it often closely resembles and by the efficiency with which the absorbed energy is transformed into luminescence

Photoluminescence may be either a fluorescence or a phosphorescence or both Energy can be stored in certain phosphors by subjecting them to light or some other exciting agent and can be released by subsequent illumination of the phosphor with light of certain wavelength This type of photoluminescence is called stimulated photoluminescence In contrast to normal photoluminescence which is constant in intensity as long as the intensity of the exciting light does not vary stimulated photoluminescence decreases in intensity as the stored energy is released *See* LUMINESCENCE

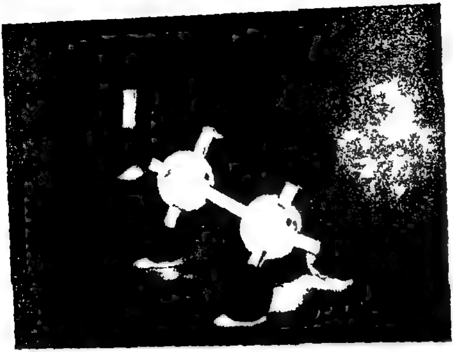
[C C K JH]

Photolysis (photochemistry)

Chemical decomposition by the action of radiant electromagnetic energy especially light Photolysis occurs in certain crystals notably the silver halides when they are exposed to radiation Here the effect of radiation is to produce a definite chemical *change resulting in the separation of photolytic* silver Photolysis of the silver halides is discussed in this article because of the extensive investigation that have been carried out on these material and because of their importance in the photographic process Actually photolysis occurs in many other material such as zinc oxide the metallic azide and to a lesser extent in oxalates styphnates and fulminate

A photographic emulsion consists of microcrystalline grains of silver bromide (AgBr) or silver chloride (AgCl) imbedded in gelatin Upon prolonged exposure to light so called print-out specks of silver form within and on the surface of the grain Shorter exposure produce a latent image which can be made visible by the process of development Experiment have shown that the latent image is p l al lv an early form of the print out silver which results after long exposure

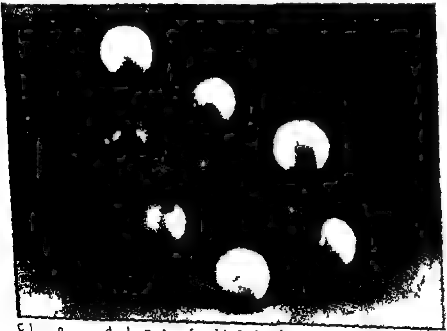
Gurney Mott theory This theory of the photographic process proposes a two stage mechanism as shown in Fig 1 In the first stage a light quantum is absorbed at a point within the silver halide grain releasing a mobile electron and a positive hole The mobile electron diffuses to trapping sights (sensitivity centers) which then ol i



U ma ked gat

P t of p nd g neg t y g r g int g l m ll

ll t m d f m the g t



C l g d l p t of m d l f thyl l h l (C H OH) m l c l h w g
l h p betw th mpl m t ry ol rs (E stm K d k)

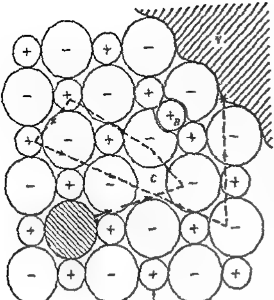
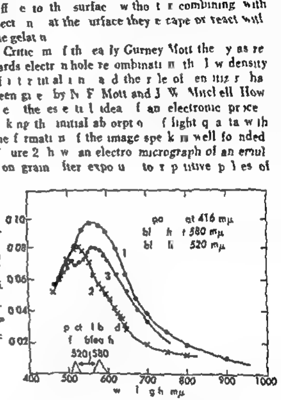


Fig 1 Sch m t p e t t f th G y M tt th ry D tt d l h w th path f a ph t l ct wh h v t lly t pp d th c ty of s l p ck N Th t tt l l n B h m p to r fz th h g f th l t d th t dd t th l p ck (Aft J R H y d W Sh k l y)

Fig 2 El ct m og ph f l hal d mul o g p sed o pett p l f light d t l ct f ld E. Cl d l th g l t f th ght r be d t x pe f b m f m th g f pou m h l w d pl d t th l ft by th l t f ld (Aft J F H m lt d L E B dy)

n the s rface f th grain In the econd tage the trapped (n gatively charged) el ctr n i ne tr l zed by an inter titial (po t vely charged) il r i n which ombines with the electron to form a ilver atom The il er tom at th sensiti ity cen ter is apable of trappi g a e ond electr n after which the proce repeat it ll cau ing the ilver sp ck to g ow It is as um d that th po iti e hole d ff e to th surfac w tho t r combining with elect n at the urface they e cape or react with the gelat n

Critic m f th ea ly Gurney Mott the y as re gards electr n hole re ombinati n th l w density of i t r tit al i n a d the r le of en itiz r ha been gi e by N F Mott and J W Mitchell How e the es e ti l idea f an electronic pr ce h k ng th initial ab orpt o f light q a ta w th the f rmati n f the image spe k m well fo nded F ure 2 h w an electro micrograph of an emul s on grain fter expo u to r p titive p l es of



Fg 3 C l h w th f m d k g p duc d t m t mpe t 0.37-cm th k AgCl cry t l by b o pt n of 4.2 × 10 ph t s/ m at 416 mμ Up t d p th d k g p oce d w th h gh ffi cy t a l l wh h dep nd po mp ty c te t ill m n t w th the b d t ll how p d bt h g h w by 2 d 3 Op t l d ty g l t $\log_{10} I_0/I$ wh I th n t ty f cd t light d I t th t ty of t ons m tt d light (Aft F C B w d N W f)

l ght and t an lectric field The p t out l e p k o u one d b a f the a ti n of th ele tr c field nd th x r mental e de c fo p s ti e hole m g t o n the pp s te di e t F rmati f th latent mag n a f st em l on nt n ng en ti ers is highly ompl e ted nd s th ght to l e th ole of such t u tu al impe f ti n di l o s a d jog n d l t n For add t n l i f rm t n n l t nt mag f ma t s PHOTOGRAPH

Large crystals Th ph t ly s of la ge ry t l f th s l hal des ha b en t d d i c s d r bl det il Wh n nt p eing th e ult n ngl ry t l t be mes n c s ary t d t g i h b twe n da ken ng p od d by l ght in th of

surface A pure crystal of AgCl will not darken appreciably upon exposure to light absorbed below the surface On the other hand crystals which contain small traces of impurity particularly copper in the monovalent state darken with high efficiency up to a saturation level which depends upon the amount of impurity present Figure 3 shows the small amount of absorption for darkening of this type which occurs in the early stages of exposure Here the extinction of light arises primarily due to absorption Prolonged exposure however produces darkening near the surface which shows considerable light scattering The centers responsible are similar to the colloidal metal particles formed in alkali halides by coagulation of F centers during heat treatment *See* COLOR CENTERS PHOTOCHEMISTRY [F C BR]

Bibliography S Fujisawa (ed) *Symposium on Photographic Sensitivity* vol 2 1958 W E Garner (ed) *Chemistry of the Solid State* 1955 C E K Mees *The Theory of the Photographic Process* 1954 J W Mitchell and N F Mott The nature and formation of the photographic latent image *Phil Mag* [8](21) 1149–1170 1957

Photometer

An instrument used in making measurements of light In general photometers may be divided into two classifications (1) laboratory photometers which are usually fixed in position and (2) portable photometers which are commonly used for photometric measurements outside a laboratory Each of these two classes may be subdivided into visual photometers and photoelectric photometers These in turn may be grouped according to function such as photometers to measure luminous intensity luminous flux illumination photometric brightness light distribution light reflectance and transmission color spectral distribution and visibility

Visual photometers Most visual photometers use a Lummer Brodhun photometer head or some adaptation of its principles The Lummer Brodhun photometer head is an optical device for seeing two sides of a white diffuse screen at the same time On looking in the eyepiece the observer sees a circular or oval field composed of a pattern whereby adjacent parts are illuminated by light reflected from the two sides of the screen Figure 1 illustrates the principle Light from the two sources I_1 and I_2 to be compared falls on the white diffuse screen with sides s_1 and s_2 and is reflected in part to mirrors m_1 and m_2 and thence to the photometric prisms A and B The central rays pass through the prisms while the outer rays are reflected by the prism Concentric fields are thereby formed an inner field by light from I_1 and an outer field by light from I_2 The photometer is said to be balanced when both parts of the field are of equal brightness

A more accurate type of Lummer Brodhun photometer head is shown in Fig 2 This differs only in the photometric prisms which are fashioned to

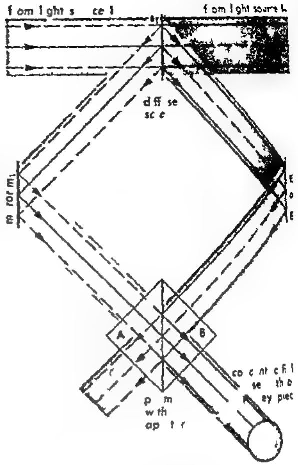


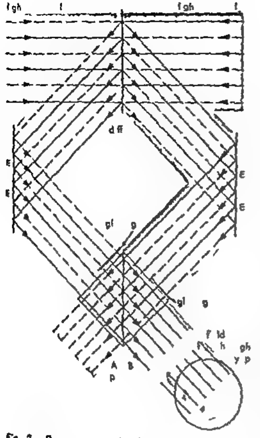
Fig 1 Diagrammatic sketch of the Lummer Brodhun equality-of-brightness photometer

give a photometric field in which a and d are illuminated from light I_1 and b and c from I_2 Clear glass strips g and g are added to absorb a li[ttle] amount of the light illuminating the fields b and [c] This type of photometer head is balanced wh[en] parts a and c are equal in brightness (luminan[ce]) and when b and d are equal in contrast agai[nst] their respective backgrounds The Lummer Br[od]hun photometer heads are incorporated in bar p[ho]tometers integrating spheres distribution p[ho]tometer and portable photometers where vi[sual] photometry is used

If there is a difference in color between the two light sources difficulty is experienced in making a direct comparison as in the Lummer Brodhun principle and a flicker photometer is often used

Flicker photometer In this photometer a single field is illuminated alternately by the sources to be compared The position of balance is the point of minimum flicker The rate of alternation is set fast enough that the color difference merge while the difference in luminance continue Other systems of heterochromatic photometry are based on the cascade method the compensation principle and the use of filter

Illuminometer An illuminometer is a visual portable photometer A typical illuminometer is shown in cross section in Fig 3 Here the light entering is balanced against the light from the comparison lamp by means of a Lummer Brodhun head



Fg 2 D g mm t k t h of th L mm Brodh t e t ph t m t

m wed th gh th eyep ec Th b la ce p nt r hed by m ing th c mpari o lamp l ng th t b A c ntr l b x uppl e a c l b t d t to th c mp ison l mp d al brated filte m y b in rted n the l ght path to t nd th ge f th n t m t

Brightness meter Thi n t me t f r me su g ph t m tr br ghtnes lum an e may b e th of the u l ph t lect c type The v s al type (F g 4) a ll-conta ed n tr ment p r m g the s m ba t p ple a the illumin m t pt th t n th br ght ess met r th balance po nt e h d by t ti g a ci ula ab pt o g ad e t b t ee th mp n lamp nd th ph t metri h d The ll m om te m y al be u ed t me ur ph t m t c b ightnes s. Th photoelect i type al portabl a d on t n t lly f ph t t b n ampl fi r to cr a th e t tp t a d mi amm ter al b ted t d d re tly th l mina f the u f e i wed

Photoelectric photometers Ph t m ters s ng barr l ye lls a d ph toel ctric t be clas fied a gh t le t phot m t Si c th ba r l e ll ge te th wn cur nt d ne d n batt ry f ope at they a be u ed e th r t th l bo at ry port ble in t me ts f th f ld Th ph t t be ph t m t n th th r h d q e batt ry oth e ternal pow pply d a u ed ma ly f r l bor t ry w k Both types of cells m t be fitted with the orrect f lters n th t they will dupl cate the tand a d lumi os ty c rve of the eye

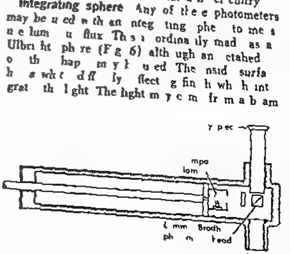
Ba ri r laye cell photometer This photometer is so po t ble and ea y to u th t it h s almost m nopol ed fi ld measurement since ts intro du t on It on ists of ba rier lay r cell which generates a sm ll electric urrent (about 1 or 2 m c oamp er /fo t ca dle) when light or other ra d a t ene gy ne the v s ble range fall on it and a micr ammeter or galvanometer to measure this cu r nt M d rn barrier layer cells generally u e el n um a the l ght n iti e material nd are ugged in c nstructi n The m cr ammeter should ha e a l w res stan e (100 hms r le s) bec u e the output of th cell is approximately linea nly fo low v lues f e ternal circuit re istance The photometer sho ld be co r cted to orrespond to Lambe t c s ne l w of incide ce (s PHOTOMETRY)

In th s type f cell the current reaches its final alue after a short time delay due t the re ult of an adapt t n eff ct and al is influenced by tem peratur Both ffects w ll b minimum with low xte nal res t nce Figu e 5 illust ate a portable type of b r ier laye c ll photometer

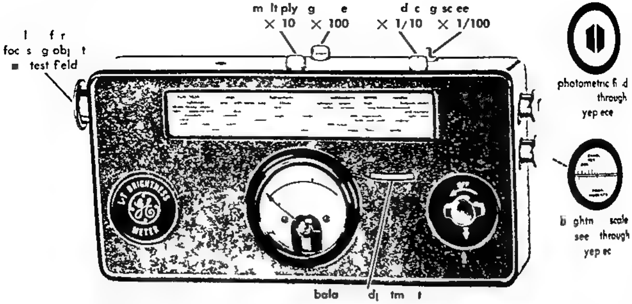
B rrie lay r cell ph t meters ar extensively u ed a phot graphic d to d t rmine proper l ght ng d ame a lens d phragm openings (*see* PHOTOGRAPHY) F r s ch applicat ons the inst u m nt is cal b ted n a arb trary cale A s mple m n al c mpute s ft n n l ded *to perm t con* erti g the meter re d ng nt th proper dia ph gm open g and e re time fo a gi en type of f lm

Phototub photomete Thi phot meter ha it lements a phot electric tube an amplifier to i c a e its t ti ty a galv n m ter r *other* suitabl mete b tteries and cu t rra gements *to gi the d* ired a ur cy In alibrat on the dark c r e t, or the cu ent flow ng when *the t be* r t *ill* m nat d is a mp tant f ct and hould be ubt acted o el m nat d b ci cuitry

Integrating sphere Any of the e photometers *may be u ed w th* an nteg ting phe to me s u e lum u flux Th s i ordina ily mad as a Ulbri ht ph re (F g 6) alth ugh an ctahed o th hap m y b u ed The nsid surfa h *a wh t d ff* ly flect g fin h wh h int *grat* th l ght The light m y c m fr m a b am



Fg 3 Esse t l of Ma h th ll



F g 4 A self-co ta ed v sual br ghtne s m te (*Gene al Elect* Co)

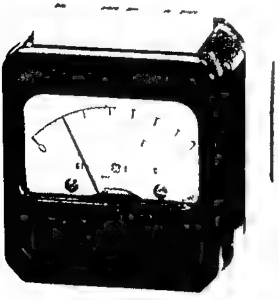
projected into the sphere through an aperture or from a light source in the phere it elf The integrated light is then measured by a suitable photometer head

Reflectometer This instrument al o called a transmi ometer combines integrating spheres and barrier layer cells (Fig 7) The reflectances of a surface may be determined by measuring the total light reflected from that surface when a beam of light strikes it in compari on with the reflecti n from a standard urface The transmittance can be measured by placing a sample of the material in the opening between the two spheres one sphere containing the light source and the other the light measuring cells

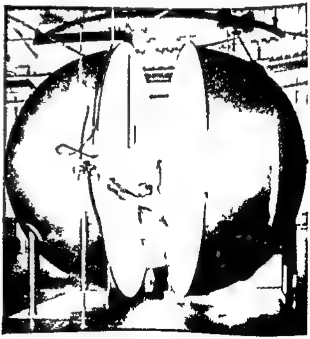
Distribution photometer The distribution photometer or goniometer measures the luminous inten ity at various angles from lamp luminaire floodlights and earchlights The light urce can be moved to the de ired angle and the light measuring head (either visual or photoelectric) fixed or the light may be fixed and the photometer made movable

Spectrophotometer Measurement of pectral energy from a light source are made by thi devi e It measures the energy in mall wa elength band by means of a canning lip and the re ults are pre ented as a spectral distribution curve See SPECTROPHOTOMETRIC ANALYSIS

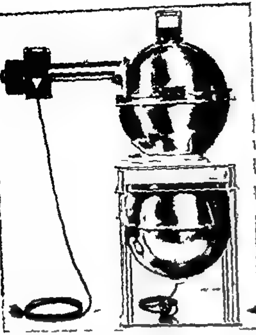
Visibility meters The e operate on the principle of artificially reducing the vi ibility of object to thre hold alues (borderline of eeing and n t eeing) and measuring the amount of that reducti n to determine the visibility by an appropriate scale



F g 5 A po t bl ba r laye l ght met w th co- a d c lo c ct o (*G al El* Co)



F g 6 Ulb cht ph fo m l g l mi o a d ffc cy (*Ge l El*



Fg 7 A fl t m t ta m m t h w g th l t g al g ph d b π l y ll ph tom t (G l Ele t C)

Fg 8 A L k h-M s b l ty m t (G l El t C)

The L ck esh Mo s bil ty m te p b bly th b t kn w d e e t to u e Th t trum nt (F g 8) o ts f tw va ble d ty filte s (f e h) that re adju ted s that a s l ta k n th o gh tl e filter b om es j t l d ce bl R d ng n cal f la t e b l ty elated t a ta dard t k

The Ce tt ell ibil ty m te a l m field per mpo d by p t n pon th al t rget Th t rg t een thr gh a n t l gr d nt filt wh h adju t l t l th t rg t det l h m s l ely pe ep t bl the ult b p e ed t m f t te ti ty

Mod n m th d f ut m t n h b f pl ed t d t ibut ph t m te M h t lled b m ched a d t p g e mpl t p gr mm g l th ph t m t huma at t nt n d t g th t t n r Th ph t met d t a a t m t lly rec ded d urv f l m nte ty also be a t m ti lly d awn [R C P]

Photometry

The b anch f cien e that deals with the m asurement of light In g ner l the in t uments u ed in the e measu ements are called ph t met r al tl ugh othe pparatu may be u d n pe i lized nsta e su h as for the d terminatio of wa e l ngth

Photometry s mo t usually conce ned with meas u eme ts of l minou i tens ty (candlep wer) l m us flux (such a light utput) lumin u flu d ty (llum n tion) luminance (ph t met r c b ghtne s) l ght d tr bution lor spectral di t ib t on and the refl cta and tran mittan e of l ght Ph tometry may even b extended to in lude vi ib lity meas r ment *See* ILLUMINANCE LUMINANCE LUMINOUS FLUX LUMINOUS INTENSITY

S n e light s d fined a radiant n rgy that i ap bl f pr duc ng u l at on photometri meas r ments e ther are made by the human eye re b d up n its i ual re po e Be au e th pectr l re p n e of human ey d ff with n d d l th Inte nati nal Commi s on on Illum nat n (CIE) ha dopted a tand rd lum n ity c rve whi h has be n a epted as be ng that f ph topic t f the n rm l eye *See* VISION

Photometric laws Many ph t metr measur ment ar ba ed upon the i ver e- quare l w and Lambe t s ne laws f i cid nc and m si n

I v rs sq e la o Th s law tates th t for a p nt ou c the ill mi at n *E* on a urface v ies d r ctly with the l m n s inte s ty *I* f the u ce and r ly as the squa f the distanc *d* between th sour d th urfa e wh n th surface n rm l t th l ght v th t i

$$\left(E=\frac{I}{d^2}\right)$$

In p act al ph tometry where th sou c i fin t s th er r i l s than 1% if the d tan e is m r tha 10 t mes th m ximum d men on of the light our

Lamb t s o l u of nc d nce If the llu n ted su f e i not p rp nd c lar to th l ght rays th llum at n the surfac ar e s the co ine f th gle f i d e θ b tw en th norm l t the fac d th n d t y Th law together w th th ve e- qu r law gi es

$$E=\frac{I}{}\cos\theta$$

the n erse q e l w f ra y rfa

Lambe t s law f mis on Th s l w i con erned w th light s r and stat that th l m ous t n ty i a g v n d ti n rad at d o r fl t d by a perfe tly d ffu i g pla e rf ce vari s s the o ine f th gle between that d e t o d th rmal to the su f ce

Photometric measurements Ph t m try m y l fied int two g ral l s e t al d physic l l l ph t m t y the ey u d d rectly gett ng a ph t m t bal n l phy

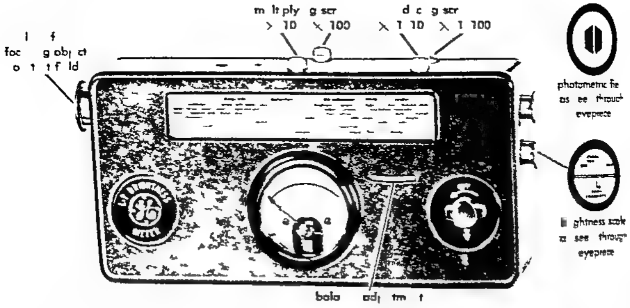


Fig. 4. A self-contained visual brightness meter. (General Electric Co.)

projected into the sphere through an aperture or from a light source in the sphere itself. The integrated light is then measured by a suitable photometer head.

Reflectometer. This instrument, also called a transmissometer, combines integrating spheres and barrier-layer cells (Fig.). The reflectances of a surface may be determined by measuring the total light reflected from that surface when a beam of light strikes it, in comparison with the reflection from a standard surface. The transmittance can be measured by placing a sample of the material in the opening between the two spheres, one sphere containing the light source and the other the light-measuring cell.

Distribution photometer. The distribution photometer, or goniometer, measures the luminous intensity at various angles from lamps, luminaires, floodlights, and searchlights. The light source can be moved to the desired angle and the light-measuring head (either visual or photoelectric) fixed, or the light may be fixed and the photometer made movable.

Spectrophotometer. Measurements of spectral energy from a light source are made by this device. It measures the energy in small wavelength bands by means of a scanning slip and the results are presented as a spectral distribution curve. See SPECTROPHOTOMETRIC ANALYSIS.

Visibility meters. These operate on the principle of artificially reducing the visibility of objects to threshold values (borderline of seeing and not seeing) and measuring the amount of that reduction to determine the visibility by an appropriate scale.

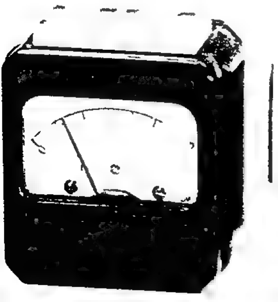


Fig. 5. A portable barrier-layer light meter with color- and cosine-corrector. (General Electric Co.)

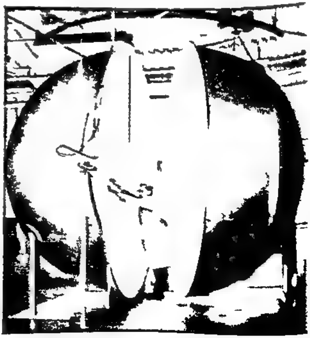


Fig. 6. Ulbricht sphere for measuring luminous flux and efficiency. (General)

The pl t metry f a lighting in tall ti n in cludes the me s em nt f ill m n t o (foot n dle) lum na th ph t metr br ghtnes of urfac r fle ta s and oth r qu ntit e Thi i call d an ill m n t n urvey Th Illumi ating Engi r ng S c ty has t nd rd d r o s tech qu of ph t metry omputat o and pres nta ti n t d t f r d ffer nt l fi at ns f lighti g in t ll ti n Th d t ft t ke th form of i o foot-candl i ol rve S ILLUMINATION

The m u ement of is b l ty onn cted w th the phot met y of a lighti g in t llati n be a e ti e m a u of the effe ti e f th lighting V ri u types f bil ty m te s g e e d ngs of r lati e b l ty ba ed n threshold val (b r d ti ne of s eng a d n t eing) Se CANDLE POWER FOOT CANDLE FOOT LAMBERT LA IBERT LUMEN LUMEN HOUR LUMINOSITY FACTOR LU MI OUS EFFICIENCY LUMI OUS E ERGY LUX PHOT [R C P]

B bl g phy W E Bar ow *L ght Ph t m t y a d Ill minating E gi e g* 3d d 1951 W B B a t *Ill m t ng E gin eri g* 2d ed 19 3 *Illum ti g E g e ri g Soc ety G r l C d t Ph tom try* 195 Illumi ting En g e ng S ety *I.E.S L ght g H dbook* 2d d 1952 J W T W lsh *Ph t m try* 2d ed 19 3

Photon

An i d bl q nt ty of ele t m gn t c e gy J C M well theo y f l ct om g ti radi t a e f lly descr bes t fe n e d ffa t o f t n r fl ti n at i t rfa es a d other ph omen a ci t d w th el t mag et c w e Th r d t ha du l cha act h we e a d in oth r i t n e it d pl y asp ts k n t those of p t l wh h are alled photo s A ph t n is sometime lled a q ntum r l ght qua t m

Ph t s e u ful f ampl unde sta d g th Compt ff t H r lect om et c s d t n lly n the f m f x y sc tte d by el ct The *x y beha e l ke pl t n f n ergy h (h Planck c n i nt s th f q ency f th adi t n) d f mom nt m h / (s the eloc ty f l ght)* In a ph t -elect on c lls n m me t m a d rgy n rved j st as f p rt cles i l l m cha i s The ph t n *loss gy nd h le s m m t m* d the ef re a l g r wa l ngth ft r the coll o The l tr n g i th e g d m m tum that th ph ton l

The ph t n a pect f r d at n also clea ly ev d nt n th ph n me n f pl t m f th mplest ngl elect n b ll th n i f a de t ph t n a d app rs t d th m tte with a cl rly d fi ed max m m EY d sc ibed by the E t n ph t el t i l w A ph t trv aw y ngula m mentum when t em tted d g n l tron c tr n t n in n atom S CO r EFFECT ELEMENTARY R I C E PHOTO N1 ION QUA TUM (PHYSICS) QU N TUM ME HA ICS [L.]

Photoperiodism in plants

A var ety of gr wth and d elopment re p n es of plants to daily d r t on of l ght and da kne s Al tho gh photoperiodi m occurs in many sp cies from the lowest t the h ghe t it was fir t ob erved i ang perm nd the tudy of th s g o p has pro ided m st of the pre nt kn wledge (s e AN GIO PERMAE) In 1920 W W Ga ner and H A Al l d d s o e ed pl tope iod m in pl nts They re p rted that pla t su h a B lo i yl ean and Maryland Mammoth toba *co requi e short days* and l ng n ghts f r fl w ring that other pla t need long days nd h rt n ght whereas still oth r pla t were eemingly *uninfluen ed by day* le gth Subsequ ntly they found that flowering was not the only day length egulated respo se of plant fo example sever l phen mena such a prod ct on f bulbs tuber and runners, colorati n of som kind of fru ts and lea es f rmati n of b ds and tl e de el pment f bud *dorma cy* are al c nt ll d by d y length

The ph omenon wa called ph t p i d m b ca it wa c n e ned w th ffect *of light on the pl t i l ion to t me* The tim mea ure was a da ly ne bei g the period either f l ght o of da kne r a at o of tl e one to th ther In g e lat tude the d ily per ods of light and d rk ry w th the e n and m t plant re pond a c rdi ly Timing of e nal resp n e by di ra t n f light s m h more con tant fr m year to y a than t m ng c ntr lled by t mp rat re rain fall s me and mly ariabl c nditi n

Terminology Certa n term are ommonly used i d c si g pf toper odi m f flower ng plants

Sh t day pl nt Thi kind f pl nt flowers best o nly when d ily l ght p riod re h rt and dark per ds lo g E amples re p nsett a soybean co kl bur a d h y nth emum

L ng d y pl t Thi ki d of pl nt flower best n o ly when daily l ght per ods a e l and da k per d a e ther h rt o absent E mples are wh t ts, ba ley beet a d poppy

Ind t mi ate d y n ut l pl t The fl w r g of th ki d f plant i i d p de t of daily du t f l ght a d da k e s Ex mpl re to- mato d g den be n

Ph t p d du t tm nt The d y length e po u e to light wh ch i *followed* by th appea an e of m p c fl wer bud (flowe n mo d)

Critical d y l gth n ght l ngth Th the day n ght length wh h diff e t ate b twe n nd t nd ducti ph top r od fo e th r lo g h rt day pl nts

Wh n ph t period m was first d sco e ed the pec fic r le of light and da k in th pr ess we e i k w b t it ha i e been hown th t the time- m ring proc es n d r ng the da k periods Sh rt day pla t a thu m re correctly long n ght pl t d lo g day pl nt short n ght pl nt Be- n f lo g u ag h w ver th t rm h rt-day and l g d y will p bably be eta ned

cal photometry a photoelectric cell calibrated to response of the normal human eye makes the measurement (*see* PHOTOMETER) In either case the photometric measurements are eventually based on the primary standard of luminous intensity which is called the new international candle in the United States and the candela in the rest of the world *See* CANDLE

This primary standard fulfills the requirements of being accurately reproducible with a radiation that follows definite laws as to both the amount of luminous energy emitted and its distribution throughout the visible spectrum It is not however easy to use so lamps known as secondary standards are carefully calibrated with the primary standard and used in its place Other lamps called working standards are calibrated with the secondary standard and are used in the laboratories for standards of luminous intensity and luminous flux

The eye cannot measure the amount of intensity of light with any degree of accuracy because of its power of adaptation It is a good judge of equality however when adjacent surfaces of much the same color quality are viewed simultaneously In visual photometry therefore the eye views a photometric field that is made up of two parts each of which is illuminated by one of the light sources to be compared The photometer is then manipulated so that the two parts are equal in photometric brightness The photometer is then said to be balanced Balancing may be accomplished by (1) moving the photometer head in respect to the light sources (2) moving one light source while holding the other source and the photometer head fixed (3) introducing a disk of graduated density between one light source and the photometer head or (4) otherwise adjusting the illumination on the two parts of the photometric field in a measurable way so that the photometer is balanced

An example of the simplest type of photometric procedure is illustrated A movable photometer head is mounted on rails between a working standard lamp and the test lamp all three being in one straight line This is called a photometer bench The photometer head is moved until the luminances (photometric brightness) of the two sides of the head are the same The luminance of a surface equals the illumination E times the reflectance ρ or from the inverse square law $I\rho/d$ Since the luminance are made equal

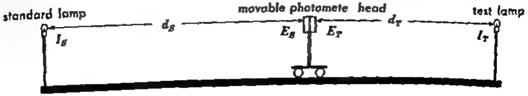
$$I_T\rho_T/d_T^2 = I_S\rho_S/d_S^2$$

where subscript T identifies quantities relating to the test lamp and subscript S identifies quantities relating to the standard If the reflectances are equal the luminous intensity I_T of the test lamp can be determined by

$$I_T = \frac{d_T^2}{d_S^2} I_S$$

Such visual methods are the basis of photometry and were the only ones used formerly both in the laboratory and in the field The accuracy of visual photometry is limited however because the response of one observer s eye may differ from that of another observer as well as from the theoretical normal eye The development of physical photometers in the last few years eliminates the errors caused by the uncertainty of the human eye Physical photometers are quicker and easier to use but they require frequent calibration they vary with time and they require special filters or other means of making their spectral response characteristics correspond to those of the theoretical normal eye of the standard observer Both types of photometry are still used but the physical photometer (especially using barrier layer cells) is more popular and is used almost exclusively in field measurements of illumination

Photometric surveys Photometric tests are made of light sources lighting units (called luminaires) lighting materials and lighting installations The measurements made of light sources and luminaires are of luminous intensity (directional candlepower horizontal candlepower spherical candlepower) luminous flux (output in lumens efficiency) photometric brightness or luminance (foot lamberts candles per square inch) light distribution (distribution curves in one plane isocandle curves) and spectral distribution The efficiency of a light source is generally expressed in lumens per watt The efficiency of a luminaire is expressed as the ratio in per cent of the lumens output of a luminaire to lumens output of the light source within the luminaire A photometric report on a luminaire can include candlepower distribution curves zonal light flux distribution total lumen output efficiency of the luminaire photometric brightnesses (luminances) at significant angles coefficients of utilization and other data pertinent to the luminaire The photometric tests of different types of luminaires (such as indoor lighting equipment street lighting units and searchlights) require individual photometric techniques apparatus and methods of showing data but they all follow the same principles



Diagrammatic sketch of a photometer bench

Fg 2 V w f p ct g ph w th f t m ed t h w p rt f pt l y t m

h w Fg I S I rv h ch r I t the n gy f c d t l ght f g n p e t w e l gth ll d a t p t m rs Th d t f th rv m f m f lly p f rm d phy l g l p m t t wh h l ght f kn wn w l gth d e gy ppl d t pl t n th m ddle f th l ht t p e t p m t fl g e d t th ph t p d p f th pl t S l en gy l l m t h h d som too l w gt t d ff t l t f pla t t h w l gth g th t a l able est m t n be m de of th m m m gy q ed f p te h g

l ight f l gh p tr l p ty r d d by e l d ff nt meth d It m y b bt i d by a i g th l ght f m b th h two-p i m pect g ph (Fig 2) wh h t d ta f b t 40 ft p d p t m 3 m h gh d b t 6 ft n w dth f m the l t t th ed Le wh le pla t g e th d k p r od t pt by pl c g th m al th p trum t fi d t t n f wh h th e g d w l gth ng k own (F 3) t t p t m rs met m g l t th tu f th mp d that p t l g l t th ph toch m l t Spe l ff t f l ght f m t p t f th t m h th t f th d f th pl t p ct nd tes th t p m t p t th t t l l h d l ght U d d l um t es th t p t m f th p so l ly mble th b pt p t m f th t p gm t t g f m t b t th bo-hem l t f tl p gm t B th ff t g f th p t m f th ph t p r d t m l th d t b l d d th t tl t p gm t p babl bl H we f gm ted mp d h g h pt p t l sel m l t the ph t p d a t pect h bee t ta ed f m pl t p d ll po pl t Ph t ght h let p l h h l d ntly bl g lg h ls pt p t m f th typ d ted b ph t p od t p t (CYA-NOPHYTA) Bl e g e al h we r are ot k own to be n ti e t ph t pe d nd ph to-pe i d lly ti e l l plants ot kn wn t c nt n phyc cy A mp d f imilar natu e n th l i the mo t p b bl form of th p me t

The everal ct p t m urv f l ng and ho t-d y pl nt r e t ally alike Thi similar ity i dicates that the primary photoreaction i the two k d f pl nt the same e en though the eff ct of dent l t tm t d metric lly p p t I te g ftin of lon d h t d y pl t bef ide t ty f th i action spectra w e t b l hed d c tes th t th type h ld n day l gths p m t e of its own fl we ing o ld i d fl wering n g ft p t f the opp te d y length type e e th gh the l tt wa ub-je t d t phot p d n t p m ti e f fl w ring S h e p me t h w ide t ty n d t l of the fl w p o e n l n and h t day plant th ti p ctr m xpe m t h w th t the de t ty t d to th pre d g l ht r a tio that lat the d t l

Photoresponses Comp ris n f t n pectra l abl meth d of tabl h g th id tity f ea t th t us d ffe t pl nt p n n mp rt t f n ti f th e a t spect m m as m t Th m th d is ed t h w th t the pl t t n th t r g l t fl w ri g of l n nd hort day plant al r g lat e al th pl t p Alth h the l tter a e t mm ly eg ded a ph t p d c they are m ti ed b fly h be f th tr but n that k owl dg b ut th m m k t nde ta d n of ph t p i d m Am g the e p ns a the germ t f l ht ti ed s m feat r f th l t n f fr ts p r pe n a d r t th m t f g owth l n th m de by th t r d a f s m kt d f pla t

Th g m n t f e d h s th e f G a d Rap d l tt p m ted by l ht e pe lly r d l ht The t p t m f mot of g rm t m l t th a ti p t f u l t f fl w g th t th l ght r a t an be

Fg 3 L f yb pl t f l pl f pect g ph All l pt t m l l fl t F th d mp d l f w d t b g g f p m t

General description Information descriptive of *photoperiodism is available for a wide range of* plants and from it can be gathered certain general facts For example critical day lengths vary with species or even varieties and day lengths favorable to flowering of long and short day plants frequently overlap Thus a short day cocklebur may flower on photoperiods of 15½ hours or less and long day *Hyoscyamus* on photoperiods of 12 hours or more Plants also differ markedly in the number of flower promotive photoperiods they require for induction For example cocklebur needs only one such photoperiod under ideal conditions Biloxi soybean needs two or three and chrysanthemum requires several

The leaf blade is the portion of the plant that reacts effectively to photoperiod that promote flowering A single leaf exposed to long dark period may induce flower bud formation on a short day plant even though the rest of the leaves of the plant are on short dark periods This finding shows that flowering results from the action of a positive flower inducing stimulus generated in the leaf during long dark periods rather than from the suppression of a stimulus for vegetative development by long dark periods

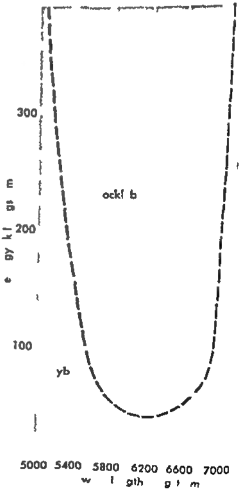
Although flowers form at a distance from the leaves the flowers develop in response to something that happens in the leave during the dark period A flower promoting product generated in the leaf possibly of hormonal nature apparently moves to the growing points where it controls differentiation of the flowers (*see* PLANT GROWTH PLANT HORMONES) Migration of enough of this product from the leaf to the growing point to effect floral induction *in many plants require that the leaf* remain attached to the plant for several hours of the photoperiod following the long dark period In cocklebur for example no flowers form if the exposed leaf is removed at the close of the long dark period but flowers form abundantly if the leaf is not removed until about 8 hours later

Darkness must be complete to be effective on photoperiodically responsive plants a very small amount of light nullifies its action Illumination greater than 0 02 ft candle of incandescent filament light throughout the dark period inhibits flowering of several kinds of short day plants The dark period moreover must be continuous to be effective an interruption near its middle as brief as 1 minute and with light energy equivalent to less than 50 ft candle minutes of incandescent filament light prevents flowering of plants such as poinsettia and soybean The brief period of light thus has consequences that continue for several hours

Nature of the light reaction The various responses of plants to day length treatment are descriptive of photoperiodism but knowledge about *them* does not immediately lead to an explanation of the processes Although the biochemical reactions involved in flowering are complex and are almost completely unknown *it is* probable that the chains of reactions leading to flowering of a photoperiodically sensitive plant and an indeterminate *one are very similar The chief* difference lies in the fact that the course of the reaction as judged by the flowering response can be completely diverted in the photoperiodically sensitive plant but not in the indeterminate plant by a light reaction of very low energy

The nature of this light reaction has been studied in considerable detail and some progress has been made in understanding how it works The most significant and to the experimenter the most useful information about the reaction is that it is reversible *by radiant energy It goes in one direction* if the leaf is irradiated with red light (about 6500 A) and in the other if the leaf is irradiated with so-called far red or near infrared light (about 7350 A) If given in the middle of a long night red light acts to prevent flowering of short day plants and to promote flowering of long day ones Far red in each case counteracts the action of red

Action spectrum of photoperiodism The maximum effectiveness of each of these reaction is at the wavelengths mentioned in the preceding section but other wavelength regions of the spectrum are also active For example the relative effectiveness of various wavelengths of light in causing the reaction that has its maximum near 6500 A is



Fg 1 A t p t m c e h w g e gy re- q ed fo h b t on f flowe g f two h rt-d y pl t s yb o d ckl b

hat t p b bly ope tes as an e zyme other e gy tra f rn g devic

Th ti e p gm t phytoch me was dete ted l e tis e by a pecial spect photometric o- ed 1959 d w tracted but t yet p ri fied nd identified by e ly 1960 F rther study f th tr cted p gme t m y cl fy the nature of the primary photo ction a d le d t u de ta d g of the b ochemin l steps in ol ed in flowers g d the ph t period c responses The latter does not ily f llow howe er Ide tificatio of bl phyll th ph t cti pigment in photosy the- f r e ampl d d not markedly imp d t nd g f ph t synthesis The e t ction of phytochr me h weve re p the subject of pho t p od m a d el ted phot po ses to st d es f a type n t p ev sly po ble

M y w rk h e shown effects on fl wering f a s t u d a other k ds of m po ds th t infl e c pla t growth a d flowe g V ry little i known bout th way th e sub t ces op at t th effect Indeed whether the ffects res lt f m th d e t p rt p t o of the e b ta m th fl we reg lat g rea t ons or f m th m e g er l nfl ce gr wth is ot l ar Neverth le a us w ke are curr ntly d g pert e t exp rime ts i olvi g appl cat o s f the hem al t e tme t and the phot nd ti da k p riod i a u ly timed que ces Such e rime ts w ll t l t d te the de in whi h chem al t e tm t d the phot eg l ted re- a ti s e r s g th ir omb ned effect nd may rev l f rther f ct ab ut th r th r ct ns l d g to flower g th w ys wh ch th e r u gr wth egul t ng s bsta ce operate i the pla t. S PLANT HORMO ES

Applications of photoperiodism Altho gh the mech m f ph top ri d m s f r fr m com pl t ly u d t od m h p a t al pplic ti n s m de f the de r pt e k owledg about the phe- n m n Pl nt e t ts w ki g in pl nt br ed ing pl nt p th l gy ther fields se a tificially o t lled ph t p r d t reg l te the t m f bloom g f the pla t Th k owl dge s al o u ed by g ow s f rta n cr p pl nts parti ul ly orn m nt l es to b ng the pl nt i t bloom o t f so so s t take d a t g of fa r ble ma ket d t The p od ti n of chrys nthe- m m th U ted State depe d l rgely on rt fi l co t l of l ght d d rkne pr ct c that permi t the p od t th o gho t the y i t d f d g a f w m th n t mn (Fig 4) Oth orn m nt l wh ch th se f c t olled d y l gth pl y p t al part re sters t b rooted beg a d h d

D t b t f pl t i d pe ds t d bl t t th ph t per od c r p es Th f kn wledge bo t photop od m h served t l ly ri ecol g al p bl m The et f b d f rm t n in g e t m ny woody pl t det m d by th l h g day l gth, a d som pec c r th a ly i th mm Oth r i m tal tables p

Fig 4 ( ) Pl t f th mm Ch t C lls- t ph h g wn rth g h th h ri d y f m dw t (b) Pl t f th m k d d g g wn d th m d t pt th t th d yl ght p od w l gth d 4 h rs by rti l l ght g

bly pl y p ts n c u the n et f d rman y i om pla ts b t n m ny woody pl ts g owth stop a d b d f rm l g b f re th rri l of low ight temper t t wh h th e ev nt are ome t mes err eo ly tt buted

Sh ot lo g ti whi h is t pped by short pho- top iod i m ny p n t e m d in some kind when th y ar r t d t l g day Thus plant of C talp b g de t p p od ci g new lea a s they ar s bje ted to sh t pho- t p i d d f held o sh t days for a mo th m r th y don t e me gr wth when etur ed t l g day u le s the temper ture i sharply low e ed f l d y W g la h b n the othe h nd re ume g wth mm d t ly w th ut a y low t mp at r t eatm t wh th y re r st r d to lo g day The h b tory ffe ts o g owth app r ently c th l es be u e rem v l of the l f W g l mmed tely foll wed by s mpti f b d gr wth th gh th plant con tin n hort ph t p i d Th ew gr wth h w q kly t pped f the h t d ys a t ed S PLANT PHYSIOLOGY [H A BO]

Bibl g phy A H ll e d r (ed) *R d to B l gy* ol 3 19 5 A M rne k et al Ve n l iz ti n d Ph t p d m A ymp m *L tsya A B olog al Mis ll y* v l 1 1948 Rud ck (ed) *A p t f Sy th is d O d G uth* 1955

Photophore gland

A h ghly m d fi d i t gum nt ry gl nd whi h a e f m n ep th li l g n t nt the de m s. It be om ut ff f m t te f r g n and d l p al m rg n e mpr d f a l n a d a l ght m ti g gl d back f wh ch i p g

assumed to control both That this is true is shown by the occurrence of reversibility of the germina tion response at the same wavelength regions that cause reversal of flowering in Grand Rapids let tuce far red light reinhibits the germination of seeds which are induced to germinate by red light

A single brief light treatment suffices to induce the germination of lettuce seeds repeated treat ments at daily intervals as practiced in the control of flowering of many plants are not required For some seeds however light treatments for several hours or repeated daily treatments are required and certain workers have proposed that these seeds exhibit true photoperiodic response This view is probably correct at least the presence of the reversible photoreaction in them has been dem on trated but complete details of the photoperi odic response in seeds remain to be elucidated

The photoreversible reaction Knowledge about the reversible photoreaction drawn not only from photoperiodism but also from studies of other phe nomena in which the reaction occurs leads to the following general expression

$$\underset{\text{Pigment}}{P} + \underset{\text{Reactant}}{XR} \underset{7350\ A,\ \text{da k ss}}{\overset{6500\ A}{\rightleftharpoons}} \underset{\text{Changed pigment}}{PX} + \underset{\text{Changed reactant}}{R}$$

The pigment form (PX) resulting from the action of red light probably regulates the various biologi cal responses in which this reaction occurs Evi dence for this comes from the germination of eeds that have long been in darkness in the im bibed but dormant condition a very low energy of red light which would change a mall amount of P to PX induces their germination

Inclusion of XR and R in the reaction is forced by the fact that the relative sensitivity of the sys tem to red and far red radiant energies may be widely different in different species or even in the ame species under different experimental condi tions These changes in sensitivity are usually of a recipro al nature in which an increased sensitiv ity to red is accompanied by an opposite change in sensitivity to far red Such variations would re- sult from changes in amount of reactant present Change in sensitivity of the reaction to red and far red has been examined in most detail in seed ger mination studies but has been observed to occur also in photoperiodism

In both seed germination and flowering there is evidence that the active pigment may undergo change of form in darkness In both instances this change during darkness appears to be fr m the far red absorbing (PX) to the red absorbing (P) form In lettuce eeds m re than 24 hours ap pear to be required for effecti e change whereas in flowering the period eems to be much shorter Rea ons for the differen e are possibly conne ted with differences in the fractional amount of the to- tal pigment in the active form required to regulate the two proces es

Elongation of internodes of plants another pho- toreversible phenomenon depend markedly upon the kind of light to which the plants are exposed at the beginning of the daily dark period Inter nodes of pinto bean plants that receive far red at this time often elongate to more than three times the length of those that receive red This reaction, as in eed germination and flowering i repeatedly reversible with red and far red The three phenom ena are thus controlled by the same photochemical reaction The response of internodes to red far red irradiation treatments shows that the pigment sys- tem is present and functional in the plant immedi ately after the light is di continued a point not readily shown by the photoperiodic reaction in its regulation of flowering

Most beans are said to be day neutral with re- spect to flowering Therefore it is of special sig nificance that the red far red reaction is shown to operate in the bean plant to control respon es other than flowering Similar findings have been made with tomato which also is day neutral in pho- toperiodic response The photoreversible red far red reaction has nevertheless been hown to regu late seed germination internode growth and fruit coloration in tomato The reaction is thus clearly shown to be present and operative in plants uch as bean and tomato the reason for its failure to regulate flowering in these plants is not yet under stood

The fact that the processes leading to flowering are under control of a reaction that can be started and stopped at will opens the way to studies of the rates of tho e reactions Thus one can irrad at short day plants in the middle of dark periods that would otherwi e be promotive of flowering and th reby start reactions that lead to its inhibition The speed with which such reactions proceed is tested by giving far red at various intervals after the red If gi en immediately far red almo t com pletely counteracts the inhibitory effect of red but if gi en 30–60 minutes after red it is ineffecti e failing completely to reinduce flowering Thi is taken to mean that products of reactions favorable to flowering that accumulated during the fir t half of the dark period are rather completely de troyed by irradiating the plant with red and leaving it in that condition for approximately 30 minutes

Information has thus been obtained about the photoreaction of photoperiodism by physiological experiments e en though the beginning and end compounds of the reaction are still unknown The acti e pigment is not chlorophyll and the concen tration of the acti e pigment is known to be ex tremely low becau e it imparts no isible color to certain all ino plant which ne erthele exhibit photore ersible response and therefore contain the pigment Therefore the rea tion i one in which profound growth effects result from exceedingly small amount of photoreacti e p gment irradiated by very low light energie The am unt of pigment actively changed by the light int the form that regulates growth is exceedingly mall indicating

h t it p ob bly operat an enzym or othe ene gy t ansf rm g d vice

Th t e p gm t, phytochr m w d tected l e ti sue by p i l spectr ph t m t i pro ed e 1959 a d w t d b t ot yet puri fi d a d ide tified by e rly 1960 F th t dy f the tra ted pigme t may cl fy the n t f th primary photor acti n and lead to an unde standi g of the bio hemi l t ps i ol ed i fl w r a d the photoperiod r sp Th l tt d e t ily f llow h wev ld t fi t f chlo r phyll th phot acti p m t n ph to ynthe sis f r mpl did n t m k dly mpro e d t nd g f photosynth The e tra t i phytoch m h we pe s the bj t f pho t p riod m d elat d ph t e p n t st d f a type n t p ev u ly p ble

M y wo k ha h wn effe t flowe ing of a xins a tiau ns a d us oth ki d f com po d th t fl ce gl t gr wth nd fl weri g Very little kn wn b t the w y the e bsta p at t th eff t I d ed wh th th eff t r lt f m the d t p rt p t n f the b t ces the fl we gul t g ct fr m th m r ge l i fl e ng wth s t le Neverth le wo k rs e rre tly d g pert e t e p m t l g ppl t ns f the hem cal t tm t d th ph t duct e d k p r d o ly t med eque S h perm t will t l a t i dcat th rd wh ch th hem l tr tm nt nd th ph tor g l ted e act n u n u g the c mb d ff ts d m y rev l further fa t bo t e the the t d g t fl we g the w y n wh h the gr wth r gul t g b i es p t i th nt. S e PLANT HORMONES

Applications of photoperiodism Alth h the ech i m of ph t peri d sm i f f om m etely d t od m h p t c l pplic t o ad of the d pt e k wledge b ut th phe om n Pla t c t t w rk pla t b ed ig pl t p th logy o th fi ld e rt fi ally ntr lled ph t pe iod t g l t th tim f loom g of th pl nt Th k owledge l ed by g w r f rt op pla t part c l ly am t l n s t h g th pla t i to bl m ut f a so a t t ke d t g f f ble n rk t nd t Th pr d t f chry the n m i the U ited States d p ds l g ly o fi l tr l f l ght d d k p t e th t p rm t the p od t thr gh t th ye r i t d f d ng a few m nth t m (F g 4) Othe m me t l n wh h the e of t olled d y l gth pl y pr t l p rt t tub o oot d beg s, do ch d

D t ib t of pl ts i t ed p d t a n d bl i ni n th r ph t p od resp s Th f k wledg about ph t p iod m h served t l ly cert e l g l pr bl m Th set f b d f rm t on g t m ny woody pl t determ ed by the se o l h ge d y l ngth and n some pec es oc r ath a ly th umm r Oth m tal ables p b

F g 4 (t et t f th mm Ch t C ll s- t ph h g w rth g h th h rt d y f m dw t (b) Pl t f th m k d d g g w d th m d t pt th t th d yl ght p d w l gth d 4 h by rt fi l l ght g

bly pl y p ts a g the et f d m y in me pla ts b t in m ny w ody pl ts g owth t p nd bud form l g b for th l f low ght tempe t to whi h th e e ts a s me t me e r ly tt but d

Sh ot long t whi h is t pp d by h rt pho t p d ma y pe n t r umed n me k d wh n they a r t ed t l g day Th pl nt of C talp b g to d t p p du w l a n s th y a s bj ted t sh rt pho t p d a d f held o sh rt d y for a m th o m th y do n t es m gr wth whe r tu n d t lo g d y u les th t mpe t ha ply l w e ed f e r l d y W g l h ub n th the h d re ume g wth mm d tely w th t ny l w temp t t eatm t wh th y r est ed t l g d y Th h b t ry ff t gr wth ppa ntly o n th l s be r m l of th l f W g l mmed t ly f ll w d by e s mpt n f b d gr wth n th h th pl nt t h rt ph t p r d Th w gr wth h w s q ckly st pp d f the h t days e i d S PLANT PHYSIOLOGY [H A BO]

Bibl g phy A H ll de (d) R d ti B l gy l 3 1955 A E M r ket l V n l iz t n d Ph t pe od sm A ymp m L t y A B l g al Mis ll y ol 1 1948 D R d i k (ed) A p ct f Sy th is and O d n G uth 1955

Photophore gland

A h ghly mod fied nt g m t y gl d wh ch a es fr m p th l l g ati n i t th d m It b c mes c t ff f m its t f o gin a d devel p t l m n g mp i d f l nd l ght m tt g gl d b k f wh ch s a p g

mented reflector of probable dermal cell origin The luminous bodies occur in deep sea teleosts and elasmobranchs which live in areas of total darkness *See* CHROMATOPHORE EPITHELIUM GLAND [O F N]

Photoreception

The process of absorption of light energy by plants and animals and its utilization for biologically important purposes In plants photoreception plays an essential role in photosynthesis and an important role in orientation Photoreception in animals is the initial process in vision *See* PHOTOSYNTHESIS TAXIS

The photoreceptors of animals are highly specialized cells which are light sensitive because they contain pigments which are unstable in the presence of light These light sensitive receptor pigments absorb quanta of radiant energy and subsequently undergo physicochemical changes which are translated into nerve impulses conducted to the central nervous system

Morphology of photoreceptors While their gross structures differ widely photoreceptors examined with the high resolution electron microscope appear to have in common a fine structure featuring the presence of membranous organelles with appreciable surface area

The vertebrate eye The vertebrate eye (Fig 1) can be exemplified by the human eye The distal segment of the vertebrate retinal rod cell (Fig 1*d*) consists of a stack of disks enclosed by a membrane In the rods of the guinea pig rabbit and mouse these disks consist of two membranes 30 A thick These enclose a space of about 80 A and the disks are spaced 100–200 A apart Each distal segment contains many disks in the frog the estimated number is 1000 The disks in the distal segment are attached to a cilium which runs the length of the segment and connects the distal and proximal segments of the rod cell (Fig 1*d*) In the cone distal segment of the perch the disks are composed of a single membrane 1?0 A thick Minor variation in dimensions of the fine structure occur in the different species of vertebrates examined

Arthropods Photoreceptors of arthropods are superficially quite different from vertebrate eyes but the fine structure of receptor cells reveal some similarities (Fig 2*a b*) Of particular interest are those portions of the retinula cell the rhabdomeres which are membranous organelles of appreciable surface area The rhabdomeres of the *Limulus* eye are composed of interdigitating microvilli from the apposed surfaces of the membrane of the retinula cells in the central region of the ommatidium (Fig 2*c d*) Collectively the rhabdomeres constitute the rhabdome in the center of which is the dendrite of the eccentric cell The rhabdome is situated beneath the crystalline cone directly in the light path The rhabdome of the eyes of spiders and centipedes is similar to that of *Limulus* with minor variations In the eye of the fly the rhabdomeres are located along the central margins of the retinula cells and constitute the rhabdome which is also centrally located and readily accessible to any light entering the lens These rhabdomeres consist of stacks of hexagonal tubes the long axes of which are parallel to a

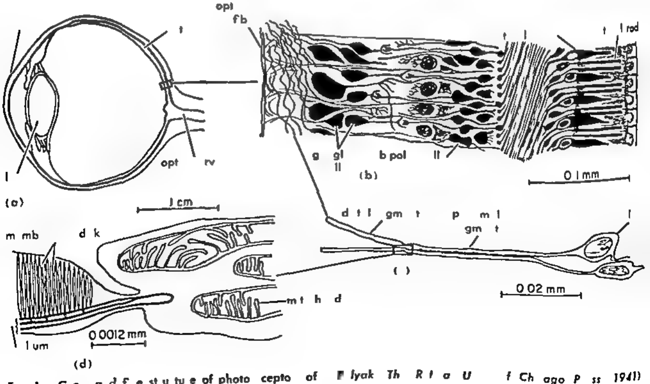
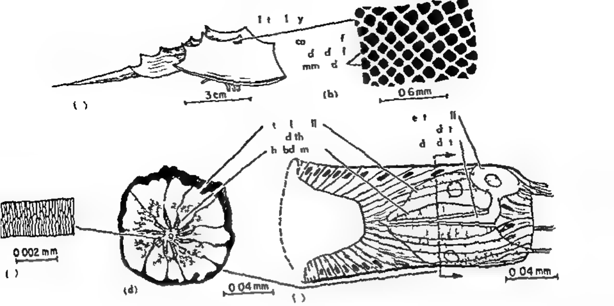


Fig 1 Gross and fine structure of photoreceptors of a typical vertebrate (a) Section through eye. (b) Layers of retina (from S L Polyak The Retina University of Chicago Press 1941) (c) Retinal rod (from S L Polyak The Retina University of Chicago Press 1941) (d) Rod (from E D Robertis J Biophys Biochem Cytol 2(3) 319–329 1956)



Fg 2 G d fi t ct f phot pt rs f NY A d S 74(2) 204–209 1958) ( ) Me ll th h rse h e b Lm f ( ) Lm l (b) Ey f h bd me (f m W ll Mll A NY A d ( ) L gt d l t th gh omm t d m (d) C s S 74(2) 204–209 1958) sect th gh mm t d m (f m W H Mll A

rad wh h b ts th t n la ll Th h g al tubes a e 3 0 A d m t nd e t f p r ph l m mb b t 120 A th k S me r tı ı ba tri tu e t ı th a thro-pod

V ll M ll n pl t e pt r l p e m mi n us g lle co ta g ppre ı bl u f e e The ye f th q d ntai f d h bd me wh ch apı to b e mp d f t b le Th t f P t n (F g 3) l n q e m mb u o g n lle t g fe n e t c lly arr ged l ght nd da k b d wl h t th m ke up a l phe ll dy l b t l; d m t r Th d k b nd f th ga ll ab ut 0 A th k a d ppe r t b t n u w tl th t lk f c il a h h att ch d t ba l b d w thin the yt pl m f th ec pt ell

C mm h t t Th ph t pt r d bed h ı mm th a es b l t t l ght th xt n ely d l p d a d tr at m mb g lles a d m tl fe t e E t e meml n s g lle h lsole b n d th f h t ec pt f fl tw rm *Pl* n the t pot f th p t *Eugl* d th hl r pl t f g pl t lt h bee p t l t d th r thes g ll of ph t ept t n l gl t se t p gment wl h e th ffect ly posed t n d t ad t e gy U f t f l d ect p oof f th po t l t l k g The f p gm t f rt l t od lled h d p n h bee loc l ed th d t l s gm t of the od b t th n es d a t wh n th d t l segm t th p gm t t t d

Chemical behavior of photosensitive pigments

Th l ght t p gm t f ph t ec pt s h h espo bl f th al so pt f ad a t e ergy ll pp ar to h e a m la hem c l n t tut n Rh d p the p gme t of vertebrate r t n l d n t f p t in onjug t d with a e ot n d Th l tt has l e n de t fied as r ti n C₂ H O the ald hyde f itamin A Th b pt n ma imum f f ee et ne e ı t 380 mμ whe t mb d w th th pr te n op in (m lec lar w ht ab ut 40 000) th vi al p gm nt h d p n f rmed a d the ab o pt max mum h ft t b t 500 mμ Th a m t f th ab-rpti n p te m f rh d p with th p tral en ı ty of h m d m l ht ı n nd w th that f m ny th rt b at l ely ampl at s rhod p l ght ept n by the od

Ult t t d h d p S me iden e sug t th t l od p n fom an ı t g l and h ghly o g d pa t of the ltr t u tu e f the d Tl p gm nt e t b tes 40% of the w ght f f og d o te gm nt Pola ı d light fl r ce d d ıty tudie all gge t that the m l ul r h ghly e t t d w thin the od Al th h d p m le ul h ph ph l p d mp ent wh h f t tally m d d t y the t b l t f th p gment Th at e t po b l t t th t th ph sph l pid f ct m) ep e-nt an a t l p rt f th st u tur l fab c f th d t wh ch tl hod p n m l cule b nd ı the di t l gme t

R t us me s Th bl h ng a d ynthesı f h dop ı dep d p the x t e f se eral et e ı me Th m t mp rta t pair a e ll t t d th tr t l (l O ly ll *cs* t e will wh n n b t d w th p f rm h d p lll m t n of a rhod p n s l t o re-lt n th l e f r t n f om th p oten n th all tra f m Tl m h n m of ble h g

mented reflector of probable dermal cell origin These luminous bodies occur in deep sea teleosts and elasmobranchs which live in areas of total darkness *See* CHROMATOPHORE EPITHELIUM GLAND [O E N]

Photoreception

The process of absorption of light energy by plants and animals and its utilization for biologically important purposes In plants photoreception plays an essential role in photosynthesis and an important role in orientation Photoreception in animals is the initial process in vision *See* PHOTOSYNTHESIS TAXIS

The photoreceptors of animals are highly specialized cells which are light sensitive because they contain pigments which are unstable in the presence of light These light sensitive receptor pigments absorb quanta of radiant energy and subsequently undergo physicochemical changes which are translated into nerve impulses conducted to the central nervous system

Morphology of photoreceptors While their gross structures differ widely photoreceptors examined with the high resolution electron microscope appear to have in common a fine structure featuring the presence of membranous organelles with appreciable surface area

The vertebrate eye The vertebrate eye (Fig 1) can be exemplified by the human eye The distal segment of the vertebrate retinal rod cell (Fig 1*d*) consists of a stack of disks enclosed by a membrane In the rods of the guinea pig rabbit and mouse these disks consist of two membranes 30 A thick These enclose a space of about 80 A and the disks are spaced 100–200 A apart Each distal segment contains many disks in the frog the estimated number is 1000 The disks in the distal segment are attached to a cilium which runs the length of the segment and connects the distal and proximal segments of the rod cell (Fig 1*d*) In the cone distal segment of the perch the disks are composed of a single membrane 170 A thick Minor variations in dimensions of the fine structure occur in the different species of vertebrates examined

Arthropods Photoreceptors of arthropod are superficially quite different from vertebrate eyes but the fine structure of receptor cells reveal some similarities (Fig 2*a b*) Of particular interest are those portions of the retinula cell the rhabdomeres which are membranous organelle of appreciable surface area The rhabdomeres of the *Limulus* eye are composed of interdigitating microvilli from the apposed surfaces of the membranes of the retinula cells in the central region of the ommatidium (Fig 2*c d*) Collectively the rhabdomeres *constitute the rhabdome in the center of* which is the dendrite of the eccentric cell The rhabdome is situated beneath the crystalline cone directly in the light path The rhabdome of the *eyes of spiders and centipedes* is similar to that of *Limulus* with minor variation In the eye of the fly the rhabdomeres are located along the central margins of the retinula cells and constitute the rhabdome which is also centrally located and readily accessible to any light entering the lens The e rhabdomeres consist of stack of hexagonal tubes the long axes of which are parallel to a

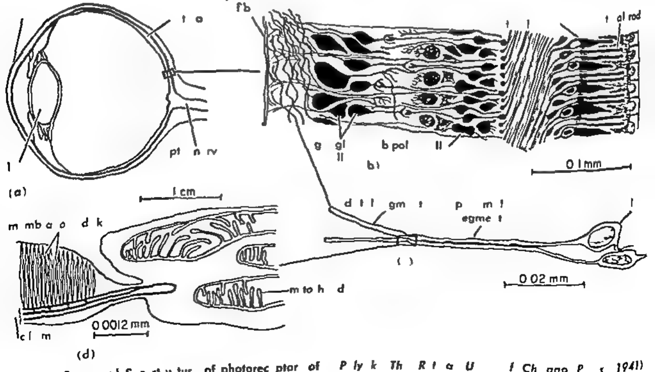


Fig 1 Gross and fine structure of photoreceptor of a typical vertebrate (a) Section through eye (b) Layer of retina (from S L Polyak The Retina U of Chicago Press 1941) (c) Retinal rod (from S L Polyak The Retina U of Chicago Press 1941) (d) Rod (from F DeRobertis J Biophys Biochem Cytol 2(3) 319–329 1956)

d ff r f m rhod psn ı its ab rpt on maximum (56 mμ) nd al ı ts much fa t r reg nerat on r t fr m c ne ops n and ll eas rets n These p operties c ou t for (1) the d m nstrable shift n ens t ity to l nger w l ngths in go ng fr m rod to c ne visio n a ariety f a im l (the P k je shift) a d (2) th b ı u ly f ste re co ry of con n it ity whi h o urs dur ng da k adapt tı A l rth p gment the ex tence of h h is nd c ted by pectr l s tiv ty data m y be synthesized by in ubat ng et n n w th one op n The pigment which lt ha an ab o pt on ma im m at 6 0 mμ and ı call d cyan p n Mo e bile d ff r nces n th pr te mo ety f ı ual p gme ts m y ha extens e eff cts up n the r pr p rt es With the rhod p n cla for x mple the ra ge of absorpt n max ma ı f om 50? mμ (f g) to 478 mμ (s me deep- ea fish) The rhod p ı of certa n fi h and of the lligator m eo e may ha r g erati n ı ad cally f ter tha th s of cattle a d f og

It ı lea th t c e p gme ts ex t whi h hav ı t a y t been ext act d It h been rega ded as essenti l th t an m l with t h matic c lor ha on s w th at least three differ nt pectr l e t ties a d r ce tly by a technique f r flect on ph t metry the ıst nce of th ee o p gm nt ın th n rm l l m n eye ha b e dem n t ated The ab nce of pe fic ones m e o e ha bee h wn to rrelate with th maj types f l r bl ndness

I e teb t The ı l p gme t of ın rte- b ha e n t b n e t n ı ly stud ed b t those ide t fied ı d ı appea to l hem ally sım lar t th e of rtebrat s The sq d has h dops n ba ed n r t n ne th the nte e t ng d fferen e th t wh the p gm t ı pl t exc t d th etınen m ty ı m es b t remains tta hed t ıts te n th p t n t d f hydr lyzıng aw y ı ert l ate rhodops ns *Phot s n t ve pigm nts* b ed up n ret n n have also been re ntly ı o- l ted f m the y f r t ea a d n ect

Electrical activity of photoreceptors De pite th ... b t the ch m try f al p gm t the mech n m by wh h th r ph tochem l a t t ı t a l t d ı t n tve mpul es m ob

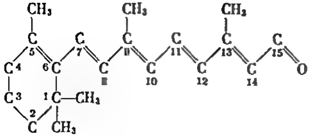
I t b t s It h been kn wn n th l t 1800s th t the rt br te r tı a ge er tes an elec t l pot nt l pon illum n t o Th c rd of th pot nt l lled th fect o eti og am (ERG) pol ph n w f rm with an ı t al rn k t mpc t (th a w e) a l ge o n pos t mpo t f l ng r l te y (th b w e) a d ... ı espo e Altho gh ıt h been f lt by som th t th ERG a ec pt potent l p odu ed by th od d es ıt s p b l le that th n ural l f th et the b p l a d g gl n cell te m h f t Nev rth les the ERG ı an ... d l u l ıt ty ıt h bee be n th t h man d k ad ptat n nd pectral ıt ty rves d t rm ed electr t gr ph ll k ee w ll ıth th bta ned u g ubj t e m a u ements The method is therefore u eful f r btain g d t n spectral ensit vity and dark adaptation in a a iety of animal and has ften been mpl yed ın preference t beha ioral tech niques The ERG h s also proven u eful clinically in th early diagno s of d ea es ın olving the etina

Unfortu ately howev r the unc rtai tv as to the ource f the ERG h s limited ts u e as *a tool in* the analy s of primary visual ev nts For th s purp e the technique of single *unit rec rding em* ploy g small electr des the m thod of ch ice This method howe er has not be *n ucce sfully* applied o far to p ıma y ory cells in the e te b ate reti a A con iderable body of *informat on* c e rn ng the re pons of et nal ga gl on cell ex sts but the g glion ell *two synaptic steps* m ed f om the pr mary ev nt of ph tore eption Therefo e su h tudı have *been pr m rily di rected toward* problems of ne ral rgan zat on ın the reti a ather than t ward the problem of phot e ept t n

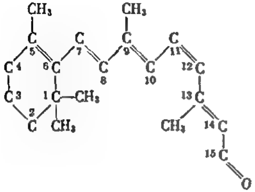
In ertebrates In erteb ate photore eptor espe ıally the comp und eye of *L mulus* the h r eshoe crab h e aff ded a *oppo tun ty* for studying the resp n e of nerve fib rs from pre m d p ımary phot rec ptor c lls Exper me ts f this so t, n which impul d scha ges fr m a s ngl *primary* erve fiber a *stud ed* ın respons to various ın t sit nd d rat o s f llum ti n deli ed ı th se e c ll ha e dem str ted (1) that the fre q ency of impul e d s h rge up to m max mum s h early elat d to the logar thm f the stimulus ntens ty (2) that w thin a cert n c itical d ı a ti n u ually som whe e between 0 1 and 1 0 sec t mul ı which th product of int n ity and d a t n t onst nt p od e d scha ges f ide tical f equ y (3) that the late cy of th impuls d s cha g decreases as th intens ty ıs rea ed Som s mila onclu on h d been each d earli r on the b f b h v oral st dies In add tion th elect physiologı al r co dı g techniques fr m pri mary n ory fibe ha bee u ed to m asure spe t al *sens ti ity* and da k adapt t n

The electr c l respo s t illum nati n in the *L mulus* mmatid um h s also been reco ded ins d gl e cells u g m cropipett le t odes Ele tri al respons eco ded ın this way fall *into* two cl sses (1) n the majority of c s s the re spon e t ll minat o s a susta n d dep l r zation on which small sp kes n ne a supe imp ed (2) ı r ly the espon e c s t of a sim l r d p lar zat n *po* wh h la g pikes are upe mp ed The depola izat on ı a l ght d c d ge e ator p t nt al wh ch pp tly *n t* ate the rs mpul e dı cha ge ı the x The frequen y f the imp l t d h rged s with n l mits d tly p p rt o al to the ampl tude f th g n at r pot t al a d th t r pot nt al ampli t de ıs p port *o* al to th l g rithm of th light ten ity

Light and depolarization It m y th s l e g n ally tru th t l ght energy ab hed by ph to-



All *trans* retinene



11 *cis* retinene

Structure of two retinene isomers

thus involves (1) the absorption of a quantum of light energy by the molecule (2) the isomerization of the 11 *cis* retinene to all *trans* retinene and (3) the thermal hydrolysis of this incompatible isomer from its site on the protein The intermediate in this process namely the complex between opsin and all *trans* retinene before the latter has hydrolyzed away exhibits an absorption spectrum displaced slightly towards shorter wavelengths from that of rhodopsin and has been called metarhodopsin

Dark adaptation After exposure to light a recovery of sensitivity by the receptor cell takes place this process is referred to as dark adaptation It is dependent upon (1) an adequate supply of 11 *cis* retinene and (2) the rate of recombination of opsin with this active retinene isomer 11-*cis* Retinene apparently is supplied partially by the action of an enzyme retinene isomerase upon the all *trans* retinene released from bleached rhodopsin. In addition an equilibrium exists [catalyzed by alcohol dehydrogenase and diphosphopyridine nucleotide (DPN)] between retinal vitamin A and retinene Opsin traps the 11 *cis* retinene which is formed to reconstitute the visual pigment

Other pigments In addition to rhodopsin several other visual pigments have been identified in the retinas of vertebrates Fresh water fishes some amphibians and certain reptiles possess a slightly different form of retinene called $retinene_2$ This, when combined with rod opsin forms porphyropsin, a visual pigment similar to the rhodopsins but with an absorption maximum at 522 mμ. The protein moiety of visual pigments too can be altered. Cones contain a different opsin which combines with $retinene_1$ to form iodopsin This pigment, which has been isolated from the chicken retina,

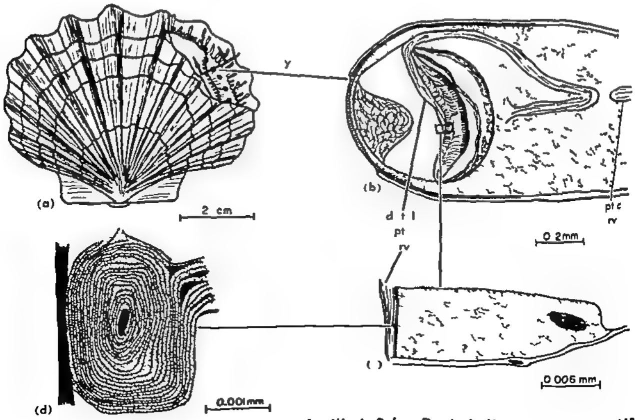


Fig 3 Gross and fine structure of photoreceptors of the scallop Pecten (a) Pecten (b) Longitudinal section through eye (from W J Dakin Quart J Micr Sci 4 49–112 1910–1911) (c) D t l s e cell (from W J Dakin Q J M os p S 4 49–112 1910–1911) (d) Appendage (from W H Miller Ann N Y Acad Sci 74(2) 204–209 1958)

where {CH O} t d f e b hydrate This re- a t es lt n the st r ng f 112 kc l of ch mical e gy i the {CH O} The oxyg n l b r ted i ph t ynthes rig n tes in water and none in carbon d xide a fact recently c firmed by exp r m nt with i t pic tr cer by n rpo at ng the t a r e ntai i g vg n i to wat r b t not nto rb d ox d

Th phot hem c l ea t n pl t synth s bel g t the typ kn wn as oxidat n r d ct ns ith a bon d d act n as the o ida t (hydro- gen ac pto) d wat r s the red ctant (hydro- g n d r) The u iq ch acte i tic f th p r t ul r id t n r d t n i that t g e th w ng di e t by rt g ch m lly t ble m t ri l t h m c lly un table prod ct Lght n gy i ed t mak th s uph ll e ct on p s- ble and a e d rabl pa t f the l ght ergy til d t ed as h m l ene gy (112 kilo- f 44 gram p m le f ed d arbon d id a i d cat d the ght d of Eq 1)

The u e f rad act e a bon (ca bon 13) as a t a h gi e n d able n ght nto th n ture f il e ym t r ch n the l ft de f Fig l It pp a th t b d de s fi t added ith th d f zyme f the type ll d car bo la e t ugar alled ribulo Rib lo e i a n t e c t ni g fi rb n t ms i the m le le a ag t x the mo e mm h e li gl e nd f t e Th a boxylai n rt hul e t a rgan a l mp d ta i g a a l vi g p r pre r d by the mbol COOH Th g p i th n att k d d id gen ted by th t l l I dr g rr od ed in th l ght p es Ult m tely th ma ial bec m t d th gh a e i s f zy i t r a t p rtly nt l a l p od t a d pa tly i to an ther m l ule of f f e h fi tu t th a ti e l

If h f k w b t the two th p rt of h t ynth the phot h m al tep pr pe h nt l rr w Fig 1) d th n y ti e t ol ed i th b d g f w i nd th he i n l yg n l ght ert l w i Fig 2)

l d fa r l f e t rn l d t ph t yn thes i m k l ly p d p es W th d q at ppl f ho d x d d fght a gr n ell will p od m h 30 t mes it wn l m xyg n ery h r Th peed f phot y thes s a be a ed ly ing the ipply f b d d th i ly r l f ll m n t th t mp i r A l ge numl of in t gati h fee dev t l t th m m nt and nt p t i f th k n t f ph t ynthest How ev d l t t th ily t llall te n l d t th r f ph t s thes d je d lso n th g n t i n d phy l g] d t s th th rg n m l t wh h r d ff ult to d f nd t l pec l

Magn tude of photosynthesis Ph t y th i th l gest gl hem l p oces arth. It n ll i t In i 100 000 000 000 t of l m t l m f m th i g nt th

gamc form The elements carbon oxygen and hy dr g n a exch ged in photo y thesis and it rever e j o e e in an e dle s ycle between the organic and the i orga ic world If we er one ing ed nt f photosy the is l ght energy is not regene ated Th er fore life earth can be ma n ta ned nly by con ta t supply of s lar energy a d its t lizat on thr ugh pla t ph t synth s

Status and importance of photosynthesis Al th gh prog ess ha been m d in inde standing the mplex me han m f ph tosynthesi s n t ts re unabl as yet r repe t th s pro e s in a tifi ial syst ms including system o tain ng hl phyll o other cell lar mater al Today e en w th fragme ts of li ing cell only min t amounts of ca b hydr te c n be synthes d i l ht from arl on d x d nd wat r

Si c fo s l f els (o l il p at) are half de cayed pr d ct of plant photosy the i f om pa t geol gic l ages it ca be a d that ot only all l fe energy b t al nearly all d t al p wer as well as all ndust al and d m tic he t have th e r ig n ph t ynthes s Excepti s r wi d a d w ter pow r nd m recently n cl ar power W nd and w t r p we w ll neve l al le t s j r ly the en rgy ma ki d d Atomic pow r h we e is rapidly gr wi g in imp ta ce Ne e thel s plant photosy th i will tin t b of g e t im p rtan t man n t nly s the o ly ou e of l i g matt and lif en rgy but l a a ou e of nd tri l p w r nd heat I t me t c b hoped h wever that ma will learn t mit te or ev n s rpa s pl ts n the d r t photo h mic l ut l zat on f n l ght f r rgy t rag and per h p f th pr d t on of f d (the e two fu t s b ng mb ed in pl t ynth)

Measuring photosynthesis The r te of ph to y th c l e m asu ed ac ding t Eq (1) e tl e by d t mi g the l m f carb n d ox d con med pe un t t me $-\Delta CO_2/\Delta t$ or the volume f ygen l b rated p r unit tim $+\Delta O_2/\Delta t$ u ing ny f th d ffi nt nalyt al lect hemical or l met meth d s table f r th e p rp ses Part cularly w d ly u d in e t wo k i the m no- m t i method f O W b rg in wh h subme g d pl ts (n llul r lg e are mo t suitable for the p p) re po ed t light in r ll cl ed e s l nn ted t p ec m man meter (se Algae Ma o ieter) If the liq id m d um i lk li e arb n d d is ab rb d i it nd n t cha g d w th th th man met the m d re tly the rat f l b t n of x g I n t l ed med the pr e h nge ed by th n mpti of a b dio d a d the l ber t n f xyge l ly bal e ea h th a d th m m te m es nl b u m e s ly l bl bon d d e t t d fr m w te th n r l t ely in oluble yg n l b d In th e th t f phot ynth e n be det m ned f m the ma m t ic read ng f the s lubil t es f the two g es e known d if Eq (1) i m d t l ect ith t me f th phot ynthet i ΔCO_2 ΔO_2 s 1) I d p d tly of th mpt ΔCO_2 d ΔO_2 r be c l ulat

sensitive pigment acts to produce a sustained depolarization of sense cells by increasing the permeability of the cell membrane and that this depolarization acts as a generator potential to initiate nerve impulses The nature of the mechanism by which the absorption of light and the chemical changes which follow it trigger this generator potential is however still a mystery

[D K V J W]

Photosphere

The photosphere of the Sun (the visible surface of the Sun or other stars) is a gaseous layer a few hundred kilometers thick with an average effective temperature of 5780 K determined from the total radiation per square centimeter The temperature is maintained by convection which brings hot material from the opaque solar interior to the surface in the form of rising columns of gas (*see* STELLAR EVOLUTION) The convection produces a small scale granular texture which is visible through a projection telescope In areas where strong magnetic fields inhibit the convection the photosphere cools and dark sunspots appear *See* SUN

[J W E]

Photosynthesis

The term literally means the synthesis of chemical compounds in light However it is used almost exclusively to designate one particularly important natural process of this type the manufacture in light of organic compounds (primarily certain carbohydrates) from inorganic materials with simultaneous liberation of oxygen by chlorophyll containing plant cells This process requires a supply of energy in the form of light since its product —carbohydrates and oxygen—contain much more chemical energy than its raw materials—water and carbon dioxide This is clearly shown by the liberation of energy in the reverse process the combustion of organic material with oxygen (*see* PLANT RESPIRATION) The light energy taken up by the pigments of the photosynthesizing cells especially by the green pigment chlorophyll is partially converted in photosynthesis into stored chemical energy The two aspects of photosynthesis the conversion of inorganic into organic matter and the conversion of light energy into chemical energy make photosynthesis the fundamental process of life on earth It is the unique source of all organic matter and of all life energy on our planet

A multistage process From an enormous amount of research by plant physiologists biochemists photochemists and physicists it is known that photosynthesis is a complex multistage process Its two main parts are the primary photochemical process in which light energy taken up by chlorophyll is converted *into chemical energy in the form* of some not definitely identified energy rich intermediate products and following this a sequence of enzyme catalyzed dark (not photochemical) reactions by which these intermediates are converted into the final products of carbohydrates and free oxygen

From a variety of experiments particularly those on plant fragments which produce oxygen from water in light but do not convert carbon dioxide into carbohydrates it has been concluded that the first step the primary photochemical process is concerned more directly with the oxidation of water (taking hydrogen away from water and letting the remaining oxygen escape) than with the reduction of carbon dioxide (adding the hydrogen taken away from water to carbon dioxide) The hydrogen separated from water in the photochemical process does not appear as free gas (H_2) rather it is added to some intermediate acceptor which ultimately transfers it to carbon dioxide by a series of enzymatic reactions Analogous intermediates must be involved also in the liberation of oxygen from some as yet unknown intermediates of the dehydrogenation of water since this process also requires enzymes This leads to the general scheme of photosynthesis shown in Fig 1 This schematic illustration indicates that the light reaction takes hydrogen away from an intermediate in the conversion of water to oxygen and transfers it to an intermediate in the conversion of carbon dioxide *to carbohydrate The net over all chemical* reaction is

$$H_2O + CO_2 + \xrightarrow[(112\ kcal)]{\text{Light energy}} \{CH_2O\} + O_2 \quad (1)$$

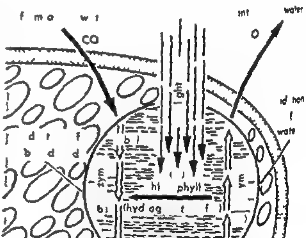


Fig 1 Schematic illustration of photosynthesis (a) Chlorophyll sensitized hydrogen transfer (b) Enzymatic reactions converting carbon dioxide and light supplied hydrogen into carbohydrate {CH O} (c) Enzymatic reactions converting dehydrogenated water to free oxygen

tr In f ct pract c lly all of the latt sto e no e e gy t ll b t merely u e l ght e gy t a t vat n int i cally un t bl but pr t cally in rt hem l sy t m

A de abl o tr rsy ha bee g i g on i about 1940 a t wh ther pl nts are cap ble of m h highe ffic en s m l ervers fo e mpl O Wa b rg la med to h e actu lly r ached a 100% e m r n effic ncy Th a i red ble would be th l m that a ompl e ted ma h e h d bee made t oper te at h gh pe d ith t a y fr ct n l es whates r

It n t imp ble that u d r m n t yet f a ly establ hed e d t n quant m r qu e me t of les th 8 can b obtai ed perhaps 7 ev n 6 but n h es lts ha e f d gener l ac cepta e by wo ke s i th field The n w of de able imp tance f the i terp etat o f the mech m of light acti n n ph t ynthes Th ed ct of o e m lec le of ca b n d ox de to the rbohyd l el req e the t sf f f n hyd g at m

$$CO + 4H \rightarrow \{CH\ O\} \rightarrow \{CH\ O\} + H\ O \quad (?)$$

A q a ti m quirem nt f 8 o m re would thus p rm t tw q tant t b ed f th t ansf r f o hyd g at m Th p t lated i som ew theo ies f the p oc by Jam F anck If t co ld be h wn th t the m n m m q nt m q ement b t t lly bel 8 u h the would be c m ten bl

Saturation light and dark reaction If the te f ph t y thesi i pl tted as a fu t on f l ght int n ty a res lts wh h h ws fi t pro port l i a e the g ad l l ght t rati (F g 2) Light at r t n an b du t a o s ses On i th l mitat n of b n di ide sup-

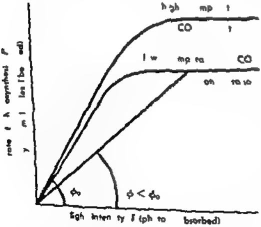


Fig 2 R t of ph ynth P t f t on t th in ty f ill mi io (f bso pt f pho- ton) f how g th ph m f l ght sat t The sa ratio l h gh wh t mpe t CO on tra io l h gh Th t ge f th gle ϕ is th atio P l th q t m yi ld t ho th highest value (ϕ_0) is f w l gh d d ea wh light satura ion sets in

ply f om the outs de Further increa f light in t s ty be ome of no u e when all c rbon dioxide m lec le rea hing the ell are u ed up a fast a th y a i Ca b n di x le c nc ntrat on act i this ca s a lim ting fact r The ame pri c pl appl es to the effect f nc ea ing arbon dioxide c n entrat on weak light when the reaction i l ght lim ted

The oncept f l m ti fact rs was int oduced into photosynthe i i 1905 It is recogn d that thi conc pt n t a pec al character tic of pho- t ynthe but that it appli s to all chemic l sy tem n which one or se eral reactants m st be c ntu u ly suppl ed f om the outs de t keep the r t n going Light can b co s der d a a re act nt i photochemi try

Wh n the upply c d tions fo ca bo d ide and light a e m t f abl the rate of ph tosyn thes t ll sh ws aturati n in espe t to both th e r abl s This s g ner lly attributed to the need fo th completio of photo ynthe is f at lea t one (and more l k ly s eral) light i d pendent *enzy matic* eact ns which can f llow or precede the *ph toch mi al tep* An zyme-cat lyzed react n ha *cert in ma imum rate* $(E\ /T)$ dete m ned by th total mou t of t cataly t (nzym) ava l able i the c ll E a d t turn ver t me T the a age t me th enzyme m le ule mu t wo k at a g temp ratu on a m lecul f th react n b trat b f e its transf rmatio completed

$$I_{max} = E\ /T \qquad (3)$$

Th seve l nzymes in ol ed in photosynth thus mpo e ce l gs on the m ximum speed at which ph to ynth s a wh l an proce d der the mo t fa o ble pply cond ti each nzyme f cti n ng a bottleneck f l m ted capacit the react on p th The enzyme which mp es the m t effect e (l west) e l ng seems to be in ol ed n the l be at on of yge rath r than in the re du ti n of c b n d x de ince the same at ti n rate wa ed al o n the o-c ll d Hill r ct on a t n of ph t y the s in whi h c b n di de d es n t t ke p rt at all as w ll be pl n d lat n th art cl

Photosynthesis in flashing light In 1932 it w s h wn h w the l ght a t n n phot ynthe i c n b s p t d f m the da k re ctio by th u f b ri f i te l ght fla he par ted by i tervals of d k e s f arabl d rat n The two m n c n cl d d f om flash ng light exp r m ts a e th t the d rk nterval between fla hes mu t be l ng th n 0 01 ec to obtain max mum yield of ph t synth from ch fl sh d that th s maxi mum y ld m pla ts amo nts to b ut on mol ule f ygen l b rated n ea h fla h for 2000 mol l of hlor phyll pre nt n the ll The ec nd res lt c n b interp eted as m n g th t the ell c t e molec le of the r t l mit g n me p 2000 chlo phyll molecul s th t the m imum fla h y eld i a m a ur f E i Eq (3) Th fi t r lt co ld be te eted to m an that T n Eq (3) b 0 01

rately by comparing the readings in two manometers containing identical volumes of the same cell suspen ion but having different gas volumes

Other analytical methods for O or CO such as chemical or electrochemical determination of carbon dioxide *infrared spectroscopy and thermal* conductivity measurements in the gas not to mention methods for the determination of the amount of synthesized carbohydrates or of its heat of combustion have not been developed to anything like the precision of the manometric method Such methods must be used however in experiments under natural conditions particularly in large *scale measurements in the field*

One difficulty of precise measurement of photosynthesis is that the reverse process respiration continuously occurs in plant cells The usual procedure is to determine the rate of respiration by measurements in the dark and add it to the rate of net photosynthesis measured in light This implies that the rate of respiration is not affected by light The be t support for this assumption comes from A H Brown s measurements with the mass spectrometer in which respiration and photosynthesis were made to use oxygen pools of different isotopic composition (O O) thus permitting simultaneous determination of the rates of the two processes (*see* SPECTROSCOPY) Such mea urements showed that respiration can be either unaffected or somewhat accelerated in light the latter particularly in blue green algae and bacteria in which the sites of the two proces es are not separated In higher plants photosynthesis is concentrated in chloroplasts whereas respiration occurs mainly or exclusively in the urrounding cytoplasm (*see* CYTOPLASM)

Le s direct methods occasionally led to conclusions that the rate of respiration is drastically changed in light either decreased or stimulated but the e conclusions are much less reliable than tho e derived from mass spectroscopy

There is no doubt that respiration is sub tantially increa ed after a more or less extended period of photosynthe is when a previously starved cell becomes enriched in photosynthesized sugars which can serve as *respiration substrate*

Changes in re piration imp o some uncertainty on all measurements of the rate of photo ynthe is This error is le s significant when photosynthesis is measured in strong light since under the e conditions its net rate may be 10-20 times higher than that of respiration as measured in the dark The respiration correction becomes much more important *when mea urements* are made in weak light a type of study important for the determination of the maximum efficiency of photosynthesis Under the conditions a relatively mall change in the rate of respiration during the experiment may introduce a ignificant error into the calculated rate of photosynthe is In addition under the e conditions chemical interaction between re piration and photosynthe is becomes imp rtant intermediate products of respiration may be utilized for photosynthesis instead of external carbon dioxide and vice versa

Turnover of photosynthesis on earth The total turnover of photosynthesis on earth has been roughly estimated in two ways by averaging the *yields of organic matter per unit area of field*, forest steppe and ocean and by determining the average utilization of incident solar energy by vegetation covered areas Both procedures lead to numbers of the magnitude of a 100 000 000 000 (10) tons of carbon transferred from the inorganic into the organic state each year This corresponds to about 10^{18} kilocalories (10 k hrs) of light energy stored annually *The great* ource of uncertainty in the e timates is unsati fact ry knowledge of the average production of organic matter in the oceans which has been variou ly estimated from about the same as to everal times greater than that of an equal area of vegetation covered land

UTILIZATION OF LIGHT ENERGY

The average utilization of incident solar energy by plant covered land during the vegetation period is of the order of 1% (*see* SOLAR ENERGY) This proportion is rai ed to about 2% if only the ible light absorbed by the plant pigments (that i only light with wavelengths between 400 and 700 mμ) is taken into account About 50% of olar energy is in the far red and infrared region and i not absorbed by the photo ynthetic pigments

In the conversion of 1 mole of CO_2 and 1 mole of H O into 1 mole of carbohydrate group (CH O) and 1 mole of oxygen according to Eq (1) about 112 kilocalories of heat energy or under natural conditions about 120 kilocalories of potential chemical energy (free energy) are stored Light i absorbed by matter in the form of quanta of energy (photons) A 2% energy conversion yield mea s that an ave age of con iderably o er 100 quanta are absorbed by the pigments under natural conditions to bring about the reduction of one molecule of carbon dioxide *See* ABSORPTION (ELECTROMAGNETIC RADIATION) PHOTON

Minimum quantum requirement Under natural *conditions carbon dioxide supply is not al ays* adequate while light supply may be o erabundant for most effective util zation Furthermore not all plant cells are in the most producti e phy iological state By u ing turbulently flowing uspen ions of microscopic unicellular algae in carbon dioxide-enriched water an average utilization of up to 7% of absorbed sunlight has been obtained in large-scale experiments Moreo r *under* till more favorable small scale lab ratory cond tions (ery weak illuminat on and very effe t e carbon d oxide supply to the algae by strongly tirred carbonate-bicarbonate buffer oluti n) up to 30% of absorbed light energy could be conve ted int stored chemical energy corre ponding to a quantum requirement of about 8 quanta per molecule of carbon dioxide Thi is a ery high efficiency not matched by any known photoch mical reacti n in

Two m types of chl r pl t are kn wn I some the lay ed t uctu ext d m re or le uniformly thr ugh th wh l chl opla t body (lam llar chlor pla t) In th r th t uctur s emph zed in certain yl ndri al t ns and is les p o ced b twe n them Wh n uch g an lar hl r pla t a e pe m tt d to dry ut nd d i t grate t k f lter at pr te d e and l po d c d ks b eak out f th tru ture a d appear as s pa ate cyl d al g an n the lectr n mi o- gr ph (F g 3)

Distribution of chlorophyll It generally a m d that hlo ph ll m lec les a loc ted at th t rf ces between th p t d nd th l p dic l r of the l lo pla t perhap f rm n ne- m lec le th k e h t e la rs (mo olay rs) E t m t gg t that th total a a of u h i t rf ces a hl ropl t t y t b ut ad quat to a c mmo- f t all th chlo ophyll m l ul s pre ent all wi g abo t l m μ for e ch m lec l wh h z wh t it appr im t ly n ed W th granular hl r pl t t t u llv a m d that nly the ni face with n th g a a e c ered by th p g m t

Wh t co ld be the pu p of a l min truc tu p t d t were w th a m n lay of p gment? T h pothe e ar offer d l th of h ch m y b e r t On that th t o-d me s al l mi ar tru t r eat s th best nd t n f r a y a es of th s t o h t at to ll phyll m l cul and l fo r p d rem al of the r ct n p d t Co de i g th t photo- synthes l y f th l te t m tabol process in th ell pr ly a d m al f e tant may l n mp t t ad nt ge (In t rms of umler f m lecules t n f med p u it l m p n t t me ph t synthesi an be 10 or 20 times fa t r tha pirat n) A th d nt e ma b the po b l ty l e t t n n rgy m gr t on i the p gm t l y r Th beorgt of phot m t t t a ngl hl r ph ll m lecul t f r g t nt a hort) ed gy e cited tate T m i n z tl d ng r f th d patt n f th ex t t n ergy bef t n be ed l r ph toch m l p rposes, it m y be d tageo t pe mit th e e gy t m e a o d j mp ng fr m hl phyll m lec l to tl th n re n the han f t e nt w th th a t on sub t at S h a mecha m l es n e gy migrat on i f t pc t l ted som ther ies f the pr mary ph t proc n ph t th It pl ll but by n m n p n gt

Th ec d h pothes predi ted on th p- p h n th i th p t f hl phyll m l les d t h ted n mon la r int f e- t een p l eo and l po d l m ll pr babl t mpl fied Th t d bl es d n f m d ff t types f l sers t that t ll hl ph ll m lec les n th ll e th me t y F m l t h been ggested that p t l th hl ph ll t m r les d l rr t ll a g m nt n the f m f g e- t les l tw e l m lec les

hl r phyll mole ules are m re l s ly as o iated with l po d wh le oth rs ar hydr t d The e two ki d of hl r phyll may d ff r in the r apa ty for fl ore c n e n l they may ha e d ff r nt pe hap ompl mentary fun t o in ph t ynthes s

Accessory pigments A inte e ting p oblem i the l cat n in the chlo opla t and the functi n n photo y the s of o-c lled acc sory p gments th t pigments other than chl ophyll *a* the ki d of hlo phyll p e nt i all ph tosynthet cally acti e plant In the fi st plac tl re are the ther cl l r phylls ch a chl rophyll *b* in l gher plants and gr en algae and chlo ophyll in brown algae Th n the e r n n hlorophyll us pigments l tw main typ On type i called caroteno d be u f mil rity t the ange p gm nt f ca rot A ar abl a o ime t of th se p gment is found in all phot y theti high r plant alg e and a m *bacter* (s e CAROTENOID) The s co d type c m pri e the phycob l n al alled v getable bil pigm ts becau e of the r ch mi al elati n t ani mal bil p m ts The e a e either r d p gments phycoerythr ns or blu p gment phyc cyan n Both typ s a p e t in red alga (Rhod phyta) nd bl e-gr en al e (Cyan phyt) w th the red pigm nt pre a li g in th fi t nd the blu pig m nt i the o d g up f organ ms

At fi t t wa g er lly a umed that only li ht ab rbed by chl r phyll wa of mpo tanc H w t i n w l a that light ab rb d by the yell w c rot n d a d by th bl e nd red phy ob lins an h u d by pl nt fo ph to ynthe alth gh us ally w th le effi en y than th l ght ab rb d b hlor phyll The e con lu ion we e de ed f m meas em nt f th o- alled a ti n spe tra f photo ynth s l s ch m rem nt ph tosynthe s pr du d b m n h m t l ght i lated l mean of pect opl ot m ter a d th duct o of xygen (r on mption f a b n d x de) p b o bed q nt i n of l ht (q ntum y ld) mea ur d a f ncti of wa l gth The l ed p tral a t t ns the quant m y ld f phot ynthe n h related t th pro- po t on f l ght ab o l d at e ch wa elength by th diff ent p gment n the ell M a t e nent of th ki d led to the ncl i n tl at q ia t h orl ed by c t noid e 0-80% le ffe ti e than th e ab b d h hl rophyll i ntribut g n gy t phot y th An e ceptio is the p gme t fu o- xanth l the car t o d that accou ts f th colo f l wn lgae (Ph ph yta) Th p gment p pl e l ght rgy t ph t synthe about a eff t l a the g een p gm t The red nd bl pig m ts f the Rhod phyta nd Cyan phyt a e l o h ghl ffect e e th le s or q i lly eff cti e w th ph ll d p d ng among th thi g on the h t f th alg pa t l ly th c l of th l ght i wl h the h be m d pt d

Energy transfer between pigment molecules Chl ph ll m pl nt ell i w akl scent th i m m f th l ght

precise measurements have put this simple interpretation in doubt. It seems that turnover times of more than one enzymatic reaction influence the observed effects of the length of the dark interval on the yield of photosynthesis per flash.

The use of flashing light with varying flash intensity and flash duration, with variable grouping of flash, and with varying dark intervals is one of the most important approaches to the understanding of the way in which different factors affect the over-all rate of photosynthesis through their effect on different steps in the reaction sequence.

The Hill reaction. Various observations suggest that the immediate action of light (the primary photochemical process) in photosynthesis involves the transfer of hydrogen from water (or from a large molecule into which water has been incorporated in a preparatory step) to an acceptor (primary oxidant) X. The latter is not yet a firmly identified molecule. Some believe it to be triphosphopyridine nucleotide, usually abbreviated to TPN, but it could also be another biological catalyst with a similarly high reduction potential, that is, a compound which is relatively unstable in the reduced form and thus has a strong tendency to transfer its hydrogen to other molecules.

Carbon dioxide does not enter into this primary photochemical process. It is generally believed that its molecule is first incorporated into a larger organic molecule, thus forming a carboxylic acid

$$RH + CO_2 \rightarrow R\cdot COOH \qquad (4)$$

where R is an organic radical. This acid then reacts with the light-formed reductant (XH) with the help of appropriate biocatalysts (enzymes), but without direct participation of light.

These conclusions are made plausible by consideration of the Hill reaction. This reaction is a process in which illuminated chlorophyll-bearing fragments of plant cells produce oxygen from water without concomittant reduction of carbon dioxide, but with the reduction of various less stable oxidants, such as quinone or ferricyanide. Since the quantum requirement and other kinetic characteristics of the Hill reaction proved to be similar to those of photosynthesis, it can be assumed that in this reaction the primary photochemical apparatus of photosynthesis is preserved more or less intact. In this reaction, however, the coupling of the primary photochemical process with the enzymatic mechanism which brings about the reduction of carbon dioxide is impaired by the mechanical destruction of the cell.

In 1954 with the use of C[14] as radioactive tracer, it was observed that certain organic compounds containing the tracer and having reduction levels up to that of sugars are formed by illuminating whole or fragmented chloroplasts in the presence of C[14]-labeled carbon dioxide, provided certain auxiliary substances (ascorbic acid, manganese, vitamin K) are supplied. This suggests that in the coupling of the photochemical apparatus with the carbon dioxide-reducing enzymatic system is

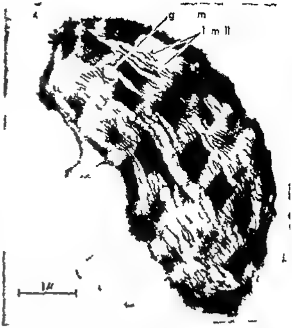


Fig. 3. Electron micrograph of a cross section of chloroplast of corn (Zea mays) fixed with osmic ... and ...iced. The micrograph shows lamellae and ... discal grana formed by the ... of re... Chloroplasts of some of the species show only lamell... no grana.

not entirely lost by the mechanical destruction of the cells or at least that this coupling can be partially restored by the addition of these compounds.

PHOTOCHEMICAL APPARATUS

The primary photochemical stage of the photosynthesis process appears to be closely associated with certain structural elements that are found in plant cells. In photosynthesizing bacteria and in the lowest truly photosynthetic plants (blue-green algae, Cyanophyta) granules called chromatophores occur which are about 50 mμ in diameter and contain the pigments necessary for photosynthesis. All other algae as well as all higher plants contain considerably larger pigment-bearing intracellular bodies called chloroplasts. In the leaves of the higher land plants these are usually ellipsoid, about 5000 mμ (0.005 mm) in diameter and 2000–3000 mμ in thickness; 10–100 of them may be present in an average cell of leaf parenchyma. *See* LEAF (BOTANY). In algae the number and shape of chloroplasts are much more variable; for example, the much studied green unicellular alga *Chlorella* contains only one bell-shaped chloroplast.

All chloroplasts fixed (solidified, usually by means of osmic acid) and dried show, under the electron microscope, a layered structure with alternate layers roughly 10 mμ in thickness. It is generally assumed that these layers differ in proportion of proteidic and lipoidic (fatlike) substances in them. The average content of the material in chloroplasts is roughly 40% and 30% respectively, as against over 90% protein in surrounding protoplasm.

t e ı l ed is called ıb l e, more pre ely a ph ph t este f thı ug r r bul e dipho phate Th e ı t ll n ertai ty wheth r the ca boxyla tı n of th mpound is normally acc mpan ed by hyd lyti ı l tt g gi ı g r e to tw m l c les of ph ph gl c d as ı d c ted ın the f llowing equ t n

$$C_5H\ O + CO + H_2O \rightarrow C_3H\ O \quad (5)$$

R b lose Ca bo W t Glyc r c d d d

F r mpl e ty th ph ph t res d es a tted The lterı t e t Eq (5) is the f rm tı n of gle m lec l l ac d with a x membe ed carbo han Ph phoglyc d h been fo nd by some w k rs t b the maın C -co t n ng p od ct afte ry l ı f (1 10 ec) ph t synth f alg e ın C tagged c rb n te However n these xpe ım t lga w r k lled at the end f expos r by d pp ng them ı t b lıng al hol d t h bee uggested that th m y ha e c u ed th dec mpo t n f 6-c b n cid ı t two mole l f ph ph glyc c a d

If ph phoglyc a d th n rmal ntermedi ın ph t synthes then t a n bl t p stu th t the e t step fter ts f rmat o t ı ı ph phogly e ld hyde s sh wn ı (6)

$$OH\ CHOH\ COOH + [RH_2] \rightarrow$$

Gly eri a id Redu tant

$$CH_2OH\ CHOH\ CHO + H\ O + [R] \quad (6)$$

Gl ald hyde Wate Ox d d red ctant

th eq at n [RH] st d fo a ed ed m d adv t gı w y tw t ms f hyd gen g th h d g n ca er [R] behind Th g red t nt m t be s ppl ed by the p m ry otoch m l p

In resp t Fq (6) run n the opp s te d ct f m ph phogly aldehyd t ph pho e d w th ph ph py id e u le tıd PN r DPN lled oenzymes I II a re c p rt Thes l tı e ed ced ı TPNH DPNH It h bee ggested that ne f these ıd n lent l lso ry med ato be een th prim ry ph toch m al dat n ed c n a d th zym t ed t n f bo di x d ph tos thes It ha bee p ed th t TPN an ed ed t TPNH b llım at d hl pla t pen th H H tı n h wes th t t lf n g p oof f th p tulated p p t f th mpo d ı ph to ynthes be m d ff ı l nt n be ed ed u de t m d tı s

O d f ult r ses TPNH t a str ng gh ed ta e t ed pl ph gly e a d t phosph gl er ld l l m g ally t ed lo l g p RCOOH t th r re l g al h d RCHO f l t the ev r r tıo l t f $TPNH_2$ by glyc r ld hyd l let ies a l H m t l en gy In expl t th ı pled w th th

f ade os ne d pho phate (ADP) and ı org nic ph sph te nto de n ne triphosphate (ATP) an e e gy t ın re tı n ın wh ch the o ıdat on en rgy ı neatly pre erved n a so-c lled h gh ergy ph ph te b d a widely used b logı l en rgy c rre cy It ha be n sug e ted that ın photo yn the ı the re ers happ n that ın th reduct on of pho ph ly eri c d to pho phoglyc r ldehyde by TPNH ı mad po s ble by coupling ıt with th ene gy supplyı g con er ı n f ATP back ınt ADP a d ı orga ı phosphate

Th ı the m st omm n version of the mech n m of ph t synthe ı at pre ent Sinc glyceralde hyde has the reduct on level f a a b hydrat ($C_mH\ O_m$ w th H O 2 1) ıts enzym t c con ve s n to suga s f r example t he o e s final prod ct r to a p ut e as CO c eptor tl u cl s ng the y le can be c mpli l d without fu the need for l ht energy by zym tic reac t n f the kinds well known from differe t e p atı n mechan ms

Photophosphorylation It ha bee h wn on bac te ıal mat rıal nd n chlo pla t m te ıal from green pl t that th s material when ıll minated n ab ce f carbo at and oxygen but ın tl e pres e ce of ADP a d n g n pho phate l ght e e gy to ynthe ıze ATP The o currence of thı ph t pl ph rylation c fi ns that the nergy re q ring ed t tep ın ph to ynth e ıs co ld p o- c d by c mbi ed ct n of a l ght pr du ed r duc ta t uch as TPNH and an ene gy ıch ph sphat su h as ATP Th could be the cas wh ther the redu tıon ubst t ıs pho ph glycer c acıd o me the a bo yl tı n p od ct In any ca e a c rb xyl group RCOOH must be red ced a d th alwa qu res about th ame e ergy whate er the natu e of the rad c l R

It h s b en f rther sugge ted that the m ch nı m by wh ch the ATP produced ıs re e sal of the phot h m al eacti on that s a o xidation f TPNH ther by oxygen or by ome intermed ate ox da t wh ch a precu sor f f ee O ın the photoch mı al p oc It known that ATP f med w th h gh effi ı n y n tl o dat on of TPNH d ng re p r t It ha e n been hy pothes zed th t all l ght e e gy ed n ph to yn the ı fir t sert d ınt ph sphat bond gy but th w ld e m to b ımpract l

Bacterial photosynthesis and chemosynthesis C r pec es f p gmented b ı ıa, s m gre n (co t ı g g ee p gm t all d b teri v d n) som p rple o r d (onta n ng bact r o- phyll s w ll mplicated rım t of te d) e ble to ynth es z g n m tte f m c rbon di x d l ght S ce the ma n b- pti n b d f b t ochlo ophyll ı lo ated ı th ne r ı fra ed wh l that of chl ophyll s ı th d p rpl b cte a h e al n ı ısible ı fra ed l ght In t a t to green pl t nd algae these g n m nn t u w t r a a r ol hyd og n f r th r d ction of carbo d ıd nd n tıı e o ly nde n tu al o dit ns pro d g th hydr g sou es n th f rm f hyd gen th ll m und fr mol l

different plants suggested its close parallelism with the action spectrum of photosynthesis In other words fluorescence of chlorophyll a in the plant can be excited al o by light absorbed by the accessory pigments with the probability of this sensitized fluorescence clo ely paralleling that with which the same light is used for photosynthe is Excitation of chlorophyll fluorescence by light quanta absorbed by phycoerythrin requires transfer of the excitation energy quantum from the primarily excited phycoerythrin molecule to a nearby chlorophyll molecule as in acoustic resonance where striking one bell cau es another nearby bell to ring Therefore it can be suggested that light quanta absorbed by accessory pigments such as carotenoids and phycobilins contribute to photosynthesis by being transferred to chlorophyll By this mechanism red algae growing relatively deep under the sea where only blue-green light penetrates could supply the energy of this light to chlorophyll which does not absorb it

If excitation energy can be transferred efficiently in the chloroplasts from accessory pigments to chlorophyll there is good probability that a similar transfer can and does occur also between different chlorophyll molecules themselves If it happens repeatedly during the lifetime of excitation the excitation energy can migrate as such over considerable distances in the chloroplast It was suggested in the section on distribution of chlorophyll that such migration may have advantages from the point of view of efficient utilization of absorbed light quanta for photosynthesis

Electron transfer in chloroplasts It has also been suggested that absorption of a light quantum in the dense layer of chlorophyll molecules may lift an electron into a state where it will be able to move through the lamella This is comparable to photoconductivity a phenomenon known to occur in certain insulating crystals which become electric conductors in light In thi way an electron may become spatially separated from the positive chlorophyll ion and it then can act as reductant in one place in the chloroplast structure (addition of electron is equivalent to reduction for example the conversion of ferric ion Fe^{++} to ferrous ion Fe) while the positive ion can act as an oxidant by taking an electron away from a substrate in another place The oxidation and the reduction products of the light reaction will thus arise spatially separated and the danger of their recombination with the loss of stored energy is reduced

This picture of photosynthesis as a process typical of a solid crystalline medium rather than of a solution is a tempting one it has been supported by certain experiments on dried chloroplast films However other considerations speak against it such as the similarity of the shape of the absorption band of chlorophyll in the li ing cell with its shape in solution and the fact that electrons can not remain free in the presence of water Perhaps the solid state theory appl es only t very small regions in the chloroplasts or grana containing 10 or 100 pigment molecule

Chemical role of chlorophyll Unle s a solid ta e picture of the primary photochemical proces in photosynthesis is assumed this que tion arises how does the chlorophyll *a* molecule ultimately in possession of the absorbed quantum of energy utilize it for an energy storing photochemical process such as the transfer of a hydrogen atom from a reluctant donor (perhaps water) to a reluctant acceptor (perhaps triphosphopyridine nucleotide TPN)? It has been suggested that chloroph l acts as a typical oxidation reduction cataly t, that is by being itself first oxidized and then reduced or vice versa with the difference that it uses it excitation energy either in one or in the other or in both of the steps Support for this plau ibl hypothesi is provided by observations of rever ibl photochemical oxidation and of rever ible ph to chemical reduction of chlorophyll in solution Studies of changes in the absorption pectrum o photosynthetic cells in light suggest that whe photosynthesis approaches saturation a small fraction of chlorophyll (up to about 0 3%) find it el during illumination in a changed perhaps in reduced state However this conclu ion need further confirmation particularly since the diffe ence spectrum from which it is derived hows al many other features ome suggestive of a rever ible change in the oxidation state of kno n ce constituents (cytochromes pyridine nucleotide some as yet of unknown origin

CARBON DIOXIDE REDUCTION

Since 1939 knowledge of the conver ion of ca bon dioxide into organic molecules such as gluco has been much advanced by the application radioactive tracers particularly of C It ha bee long assumed that the molecule CO is not reduce photochemically as such but first incorporate into a larger molecule One early di cu ed po sibility was that CO is first hydrated to carbon acid H CO_3 which then dissociates into H ar HCO ions It appears however that thi hydr tion is too slow to keep pace with the rate of ph t synthesis in strong light Undoubtedly hydrati of CO_2

$$CO + H_2O \rightarrow H_2CO_3$$

as well as its binding by conversion of carbona into bicarbonate

$$CO_2 + H_2O + CO_3 \rightarrow 2HCO + {}^{?}H$$

does occur in plants but these proce es are mo likely to provide storage pools of carbon dioxi than to serve as channels through which it ente phot synthesis The latter is now generally a sumed to occur by way of carboxylation that formation of an organic acid from a hydrogen-co taining organic molecule

$$RH + CO_2 \rightarrow RCOOH$$

By the use of C tracer it has been found th the compound RH probably is a pento e that i a sugar with only five carbon atoms in tead of the six pre ent in the more common hexo e The pen

to l ed s lled r b l se m r pr ely a ph ph te est f th uga r b l e d ph ph te Th r i t ll u rt ty wh th th rboxyla t f th compou d rm ll a mp ed by hydr lyt pl it g g e t tw molecul f phosph ly e i e d nd t d in the f ll wi g q at

$$C\ H\ O_5 + CO + H\ O \rightarrow 2C\ H\ O \qquad (5)$$

R b l Ca bo W t Glyce c
di d d

F mpl ty th ph ph te es d es m tted The lt n t t Eq (5) th f rm tion of a gle m lec l f a d w th s membe ed bo ha Ph ph lyc ri d h be n f u d by som k rs t b th m i C tai i prod i fte ry brief (1 10 sec) ph t y thes f al C[1] t gged b it H w e in these e p me i lg w killed t the e d of expos r by d pp th m into bo l ng l l ol d t h been ted th t th s m y ha ed th dec mpo t o f 6- a bo d nt tw m le- : les (ph ph ly c a d

If ph phogly e i d th n mal t rmedi at i ph t ynthes s th t s r abl t p tu l te th t th n t t p aft t f m t n it ed ti t ph phoglyce ld hyde h wn in Eq (6)

$$CH_2OH\,CHOH\,COOH + [RH\ ] \rightarrow$$

Glyc ric cid Redu tant

$$CH_2OH\,CHOH\,CHO + H\ O\ +\ [R] \qquad (6)$$

Glyceralde hyd W t Ox dized
edu tant

I th qu t n [RH] t ds fo a red ed m po d e d t gi way tw t m f hyd g n, l a g th hyd og arr e [R] b h d Th tr i ed t t m t b ppl ed by the p ma y ph toch m l p oce

I esp r t o Eq (6) n th opp te d rect f om ph ph gly er ld hyde to ph pho- gl i a d w th ph ph py id el ot d TPN DPN called coenzymes I II a a e c p rt e Thes l tter ed ed t TPNH DPNH It h bee uggested th t n f thes p d e n lent de l ri med t be- e the p m y ph t h m cal d t d d th e mat ed t f b d x d ph t thes It h bee p o ed that TPN ed ed t TPNH by ill m ted hl pl t pen n n th H ll r a t h wev th s t itself co n g proof f th po t lated p p t f th mpo r d n ph t nth be m n d ff t d t n be ed ed und h m o d t n

O d T lt r es TPNH t t o g gh ed t t t ed ph ph gly a d phosph gl ld l d m g lly t ed bo l g p RCOOH to th po l i ld h d RCHO f f r the rev rs t x d t f TPNH l gly ld hyde, ll tes a f ll am t f g l p at n th t m pled w th th

of ad n ne diph phate (ADP) and n ganic ph phate t d osin t ph phate (ATP) an ene gy t reaction n wh ch the xid ti en gy eatly p rv d o-call d h gh e ergy phosphat b d widely used b l o l energy rre y ll ha been sugg t d th t photo yn th s s the rs h pp n th t the red ction of ph ph ly i ac d to phosphoglyceraldehyde by TPNH s made poss ble by coupl g t w th the e e y s pply g n n f ATP back into ADP d gan c ph phate

Th i th m t mm n ve sion f the m h n m f ph t synthe t p t Since glyceralde hyde ha th d ct n le el f a bohydrate $(C_mH\ O$ with $H\ O = 2\ 1)$ it ymat c con v n to s a f e ampl t a he o e s final p od t to a p ntose a CO_2 ccept thus l the y l ca b ccompl h d with t furth r need for l ht energy by nzym tic rea t f the k nd well k wn fr m differe i re pi t me h m

Photophosphorylation It h be n h wn n b c t al m teri l and hl ropla t mat i l f m green pl ts th t thi m ter al when llum ted n b f c b t and oxyg n but i the pre e f ADP a d in g n c pho ph te r l ght gy to ynth ize ATP Th cc rre c of th s ph t ph pho yl ti n c firr th t the nergy e- q i g d ti tep photosynthe s c ld p o- ceed by mbined ct of light p du d reduc t nt ucha TPNH a d an e gy i h ph ph te s ch a ATP Thi could be the se wh ther the du ti subst te ph sphoglyce i cid o m the arb ylat n p od ct In ny ca e e rb xyl gr up RCOOH mu t be red ced d thi alw ys qu r s bo t the am en gy whateve th tu e f ther d lR

It h s b n furthe s gg ted th t the me ha sm by wh h the ATP s p oduced i a e r al f the phot ch mic l a t o that i re x dat o of TPNH e th r by xygen o by me ntermed at o d nt whi h s p e ur of f i O_2 in the phot h m l p es It s kn wn that ATP is f rmed w th h gh effic n y n th x dat n f TPNH d i p r t It h ev b e hy p thes zed th t ll l ght ne gy ed ph t syn the s fi t n erted to ph ph te b d n gy but th w ld m t be mp ti l

Bacterial photosynthesis and chemosynthesis C rt pe es of p gm nt d b t i m g n (e t n g gr pigm i call d b te ir id l s m p ple or ed (ta g b te hl ph ll w ll mpl t d tm nt l te d) ble t synthes g c matt f m a bo d x d n l ht S th m b- pti n b nd f b te ochl phyll l c t d in th i i f a d wh l th t of hl r phyll th ed p rpl b teri l l n ble f a red l ght l t t t gre n plant nd alg e these o g m nn t e w i a o c f hyd ge f th du t n f a bon d d d n e ly nd r t al c d t pr d g th r hyd g ces in th f rm f hydr gen 16d th lf mp nd f e m l c l

different plants sugge ted its close parallelism with the action spectrum of photosynthesis In other word fluorescence of chlorophyll a in the plant can be excited also by light absorbed by the acces sory pigments with the probability of this sensi tized fluorescence closely paralleling that with which the same light is used for photosynthesis Excitation of chlorophyll fluorescence by light quanta absorbed by phycoerythrin requires trans fer of the excitation energy quantum from the pri marily excited phycoerythrin molecule to a nearby chlorophyll mole ule as in acoustic resonance where striking one bell cause another nearby bell to ring Therefore it can be sugge ted that light quanta absorbed by accessory pigments such as carotenoids and phycobilins contribute to photo synthesis by being transferred to chlorophyll By this mechanism red algae growing relatively deep under the sea where only blue-green light pene trates could supply the energy of this light to chlorophyll which does not absorb it

If excitation energy can be transferred efficiently in the chloroplasts from accessory pigments to chlorophyll there is good probability that a similar transfer can and does occur also between different chlorophyll molecules themselves If it happens repeatedly during the lifetime of excitation the excitation energy can migrate as such over con siderable distances in the chloropla t It was sug gested in the section on distribution of chlorophyll that such migration may have advantages from the point of view of efficient utilization of absorbed light quanta for photosynthesis

Electron transfer in chloroplasts It has also been suggested that ab orption of a light quantum in the dense layer of chlorophyll molecules may lift an electron into a state where it will be able to move through the lamella This is comparable to photoconductivity a phenomenon known to occur in certain insulating crystal which become elec tric conductors in light In this way an electron may become spatially separated from the positive chlorophyll ion and it then can act as reductant in one place in the chloroplast structure (addition of electron is equivalent to reduction for example the conversion of ferric ion Fe ++ to ferrous ion Fe) while the positive ion can act as an oxidant by taking an electron away from a substrate in an other place The oxidation and the reduction prod ucts of the light reaction will thus arise spatially separated and the danger of their recombination with the loss of stored energy is reduced

This picture of photosynthe is as a process typi cal of a solid crystalline medium rather than of a solution is a tempting one it has been sup ported by certain experiments on dried chloroplast films However other considerations speak again t it such as th similarity of the shape of the ab orption band of chlorophyll in the living cell with its shape in solution and the fact that electrons can not remain free in the presence of water Perhaps the solid tate theory applies only to very small re gions in the chloroplasts or grana containing 10 or 100 pigment molecule

Chemical role of chlorophyll Unless a solid sta e picture of the primary photochemical proces in photosynthesis is assumed this que tion arises how does the chlorophyll *a* molecule ultimately in possession of the absorbed quantum of en gy utilize it for an en rgy storing photochemical proc ss such as the transfer of a hydrogen atom from a reluctant donor (perhaps water) to a reluctant acceptor (perhaps triphosphopyridine nucleotide, TPN)? It has been suggested that chloroph ll acts as a typical oxidation reduction catal t, that is by being itself first oxidized and then reduced or vice versa with the difference that it u es its excitation energy either in one or in the other or in both of these steps Support for this plau ible hypothe is is provided by observations of reversible photochemical oxidation and of rever ible ph to chemical reduction of chlorophyll in solution. Studies of changes in the ab orption spectrum of photosynthetic cells in light suggest that when photosynthesis approaches aturation a mall frac tion of chlorophyll (up to about 0 3%) find it elf during illumination in a changed perhap in a reduced state However thi conclu ion need further confirmation particularly since the d ffer ence spectrum from which it is derived shows also many other feature some suggestive of a re ers ible change in the oxidation state of known cell con tituents (cytochromes pyridine nucleotides) some as yet of unknown origin

CARBON DIOXIDE REDUCTION

Since 1939 knowledge of the conversion of car bon dioxide into organic molecules uch as gluco e has been much advanced by the application of radioactive tracer particularly of C It has been long assumed that the molecule CO is not reduced photoch mically as such but first incorporated into a larger molecule One early di cus ed po sibility was that CO is first hydrated to carbonic acid H_2CO which then dissociates into H and HCO ions It appears however that this hydra tion is too low to keep pace with the rate of photo synthe is in strong light Undoubtedly hydration of CO_2

$$CO_2 + H\ O \rightarrow H\ CO$$

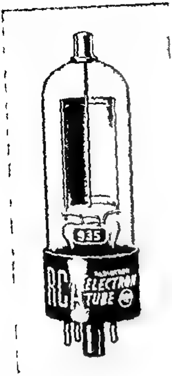
as well as its binding by conversion of carbonate into l icarbonate

$$CO_2 + H_2O + CO \quad \rightarrow 2HCO_3 \ + 2H$$

does occur in plants but the e pr ce e are m re likely to provide st rage p ols of arbon di xide than to serve as channel through whi l it enter photosynthe i The latter i now generally a sumed to occur by way f carl oxylation that i formation of an organi acid f om a hydrogen c taining rganic mol cule

$$RH + CO \rightarrow RCOOH$$

By the use of C tracer it ha be n found that the compound RH prol al ly i a pent that i a sugar with only fi e carl on atom in tea l f the six pre ent in th m re



Fg 1 Typ l m ph tot b

b dme t f th ph t ath de Th t f n de c t at n anod lt ge ff ı nt t s ı zat n, t th m lum t d c r t mea u ed at a lo ltag tl ga ampl fi t n fa t f a g ph t t be Th f to n e b twee 3 and 10 mme al g ph t n l S F ECTRIC L CO DUCTIO N GA

Ga ampl fi at r a e w th nod ll g nd w th th ı t n ty of n de t ad at on Be f ther n l a b a ter t s g s ph to t bes seld m e u d n ph t m t c appl cat s C mpl fi ti n e ses with od ltage g t b e kd w lt g wh h th t ltage t h h tl rr nt becom lf tai ı g A lf t d gl w d h rg ı a g ph totub ause p tt g f th ph toc thod nd r p dly mp r t t t

Th espo f [redacted] ph t t b t apid h ges ı l ght nt ty d s w th in ng mod l ı f ı part la ly at f qu es abo 10-15 k locy les F t rs wh h g n th peed of resp n f a ga phot t b t mod l ted d t p t a e ı t n t ı m l twee od a d thod d d l d d ry em n p od d at the ph toc thode b g t m h h a x tted t m t t l l n rg t tes. Th peed f espo n f a v uum ph to tube ı l m ted nl b l t n t n ı t m a th t l l od pa

Sens tivity to incident light Th ph tocathod f m g mult pl ph t t b el t l sen t that t m ı lect pl to lect ıc lly only wh t xposed t d at n h t g wa l gth n pec fi r gı n f th pec m Cath l l nt se ıt ty ı tl ph t l

tr urrent emitted pe unit of ınc d nt mo ochromat c ad ant p w r The pectral en ıtı ıty har cte ı tıc of a phototube e h b ts cath de radı ant ens t ıty as a fun t on of the wa len th f ad t o n ıdent pon the wind w of th photo t be

Spect al ns tıvity cha acterı t s are h wn n Fig 2 and are d gnated by stand rd ymbol S-1 S-3 etc Th ha p n toff f sen ıt ıty on the sh rt w l gth de of the curv s ı determ n d p ıma ly by th tran mı s o char t rı t c f tle gla s en l pe or window of the phot t l e The long w elength l mıt f rad nt ensıtı ty ı the th hold wa elength of the photocathode

Tl e n t ıty f a phot t be ıs m re ea l me sur d as ath de l m n n ısıtı ıty the pl otoelect ı cur ent emitted per unit of ı c dent lu m ıs fl x from p ified s urce of l ht It ıs xpre ed n microampe es per lumen The ourc mm ly u ed ı a t ng t n filam nt lamp op r t d t a l r temperatu l 2870 K Cathode ad a t a d athod l m no e ıtıvıt e e me ured with a coll mated be m of r diation per p nd cular to the window of th tube S mmar zed n th t ble a r dı nt en ıt ıtv at the wav le gth of ma m m e p e lum o n ıtı ty nd th ı format on rel tive t the pect al en ıtı ty ha a ter stıcs r p sent d ın Fig 2

Th qu nt n ffic e cy f a ph t cath d ı the number f ele tr s emitt d p r n ıd nt ph t n of a g n wa el ngth Becau the en rgy pe ph t n of wa elength λ ı hc/λ whe e h ı Pla ck s c n st t a d s the elo ıty of light ın vacuum the q nt m efficie cy at a wa el ngth λ ıs mply the

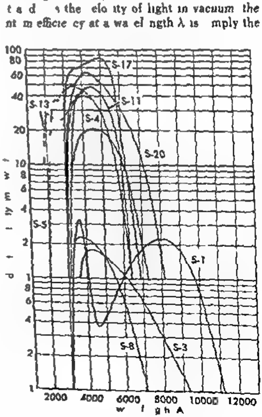


Fig 2 A g [redacted] t l ty h t t f typ l ph t t b

hydrogen or organic compound. In the latter case the bacteria destroy one kind of organic matter to synthesize another.

Because hydrogen is bound nowhere as strongly as in water, these types of photosynthesis store little if any light energy. Therefore they do not have the same significance as true photosynthesis in the transformation and storage of cosmic energy on earth. In fact all they can do is to use chemical energy where it is already available in the form of unstable hydrogen compounds. Light energy is used by them merely or mainly as chemical activation energy, as it is also used in most photochemical reactions in vitro.

It is unknown whether bacterial photosynthesis is an earlier mode of life preceding true photosynthesis or a later form of life into which true photosynthesis has degenerated in chemical surroundings providing certain sources of hydrogen. In any case bacterial photosynthesis is bound to remain limited to a few natural habitats such as stagnant canal waters, volcanic sulfur springs and similar habitats.

For the sake of completeness mention should be made also of chemosynthetic bacteria cells which can achieve the conversion of carbon dioxide to organic matter with the help of hydrogen donors similar to those utilized by photosynthetic bacteria but without the help of light. They simply burn chemical fuel by a mechanism permitting them to salvage some combustion energy in the form of reduced carbon dioxide. In the simplest case, that of so-called hydrogen bacteria, the cells change molecular hydrogen to water and use some of the liberated energy to transfer a part of the hydrogen to carbon dioxide. Whereas photosynthetic bacteria can live anaerobically, the chemosynthetic ones require oxygen to keep their energy-liberating process in operation. Some chemosynthetic organisms have developed wherever oxidizable material is present in nature, such as coal, oil, free hydrogen, sulfur compounds, ammonia, nitrite or ferrous salts. Again the question can be asked: what is the evolutionary role of the chemosynthetic way of life? Is it a predecessor of photosynthesis or is it degradation of photosynthesis under specially easy conditions of abundant chemical energy supply?

[F R]

Bibliography J A Bassham and M Calvin *Path of Carbon in Photosynthesis* 1957 J Franck and W F Loomis (eds) *Photosynthesis in Plants* 1949 H Gaffron et al (eds) *Research in Photosynthesis* 1957 R Hill and C P Whittingham *Photosynthesis* 1955 E I Rabinowitch *Photosynthesis and Related Processes* 3 v 1 1945–1956

Phototransistor

A semiconductor device with electrical characteristics that are light sensitive. Phototransistors differ from photodiodes in that the primary photoelectric current is multiplied internally in the device, thus increasing the sensitivity to light. For a discussion of this current multiplication property see TRANSISTOR.

Some types of phototransistors are supplied with a third or base lead. This lead enables the phototransistor to be used as a switching or bistable device. The application of a small amount of light causes the device to switch from a low current to a high current condition. See PHOTOELECTRIC DEVICES.

[W R L]

Phototube

An electron tube containing a photocathode from which electrons are emitted when it is exposed to light or other electromagnetic radiation. An elementary vacuum phototube consists of a photocathode, an anode or electron collector and an evacuated envelope through which radiation is transmitted to the photocathode. A gas phototube contains, in addition, an inert gas which may be ionized by electron current from the photocathode. For a description of a phototube in which the electron current is amplified by means of a secondary emission electron multiplier, see PHOTOTUBE, MULTIPLIER.

Phototubes serve as sensing elements in the detection and measurement of light and ultraviolet or infrared radiation. Phototubes also convert variations in intensity of incident radiation into corresponding variations in electron output current, as in light-controlled relay circuits and in the conversion of sound modulation of photographic film into audio frequency current, as in the sound track on motion picture film.

The fundamental characteristics of a phototube are its spectral sensitivity characteristic, or output current expressed as a function of the wavelength of incident radiation at constant anode voltage, and its anode current characteristic, which shows the dependence of anode current on applied voltage and radiant flux input. Gas phototubes do not differ from vacuum phototubes with regard to spectral sensitivity characteristics, which are described below, but their anode current characteristics are essentially different.

Principles of operation The anode current of a vacuum phototube is directly proportional to the intensity of radiation incident on its photocathode. The anode is normally connected to a positive potential of at least 20 volts relative to the photocathode in order that the anode current be limited by photoelectric emission rather than by space charge or electron emission velocity. A typical vacuum phototube is shown in Fig 1. See PHOTOEMISSION.

In a gas phototube the photoelectric current is amplified by partial ionization of a gas contained in the tube at low pressure. An inert gas such as neon or argon is used because photocathodes react chemically with other gases. At low anode voltages the anode current of a gas phototube is emission limited like that of a vacuum phototube. At anode potentials greater than 25 volts electrons emitted from the photocathode acquire sufficient energy to ionize some of the gas atoms. The total current is then the sum of the free electron current, the positive ion current and the current due to secondary electrons which are p[illegible] by ion

d ict ty ac o s r through the in ul t on upport ng the el ct odes or tube m min l and thermi n c mi on from the ph t cathode Elect al nduct ty n be r d ed to ery mall alues by plac ng the cathode and anode terminals at oppo te e ds of the tub n elope as Ilu trated in F g 1 D rk current due to thermi nic em on is p opo tio al to the area f the photo athode and nere es almo t e p ne t ally w th cathode tem perat At 25 C the th rm nic mi ion from the c um o ide-l er ph t cathode s of the r de f 10- mp/cm whe eas that of the ces um ant mo de ph tocathode is about $1 \times 10^{-}$ amp/ cm At low light level h th t the ph t elec t c u re t a d d rk cu r nt are f s m l r magn t des d crim at o between the two s re d ly ach eved by m d lat g th nput flux a d m a u ng only the ac e mp n t f and d c re t t

Types of service Ph t t bes are u ed n general l y op r t on det ct o of inten ty m d *lated* rad at n nd pl t m try R p n e f a ph t tub to a change n l ght le el cau s a rel y to l fety and wa n g dev e and n u t g rt ng eq ipm nt S n e th ch g ph t r nt may be co iderably le th 1 m oamper (μamp) in a cu m phototub a g ph t tube f eq e tly u ed t t gge a thy a t o n r f y pplc t o Typ c l appl tio in l g the det cti n f nt sity m d l ted l ht reprod cti n f d fil s nd f mile G ph t t be a mmo ly ed in a nd p o- d tio b of the r nh r nt ga *mpl fi* at n d acc ptabl a d o-frequen y espon hara t r t V c m ph t t be a u d i fa l r e f whi h h gh frequen y e p s r q d

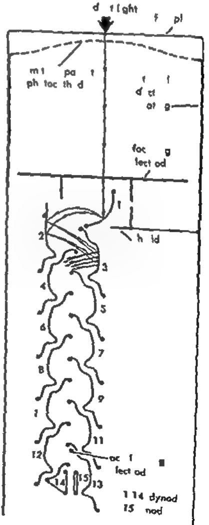
Vacu m ph t t b a u ed whe *ever lin r re* pon e t r d a t fl p t eq ed f r e mpl ph t met y nd n l r m t y I ph t m tr ppl t o s pe t al en t ty ha t tic milar t that f th h ma ey f q ently r ju d d may b appr x mated by m of pe l opt l filt s u ed in mb n t on w th ph t t t whi h a e en t e v r th ibl pect um l p tr ph t m try tw um pho- t t be may be u ed o e h ing S-5 a d th th S-1 r pon n rd t p de n ti ity t w el ngths f m 300 t 11 000 A I appl e t n h a l rm t y d th mea m nt f den ty f l r film a w b d filter a e ed w th appr p i te a u m phototube t t bl h t t m lu alu d pe d ntly f th p ti ul r sen t ty cha a ter t f th tubes These l r a t d fl f m t be t t be a re ult of m ll n tr llabl *sat* in mpo t n f th photo thod

V uum d g ph totubes re p ble of p o- d g h 11 *serv e o er th usua d f h* f pe t t mod at t mpe tu es d d at n les l T mpe t es ab e 5-100 C nd a ag thod c rrent d n t ies g e t r th n bo t 30 a mp em g d l decr a n t ity Th l f l ph t t be l m ted l rg ly by l w effu i n f ga eo contaminants which cannot be b ked out of the phototube aft r the photocath de n form d [J L WE]

B bl og aphy A L Hughes and L A DuBridge *Photoel ctric Phe omena* 1932 A H Sommer New ph toem s e cath de of high s nsiti ity *Re of Sci ntific Instruments* new ser 26(7) 725–726 1955 V K Zworykin and E G Ramberg *Photoelectri ity a d Its Application* 1949

Phototube multiplier

A phototub whi h co t i s one or m re econd ary electr n emitti g electrode or dynodes be tween ts phot c thode and output electrode also alled photomultipl er tub Electrons emitted by th photocathode initiate a cascade of econd ry emis i n from dyn de to dyn de and ult mately to the output electrode or an de Be au e of the h gh u ent ampl fi ati n thus obta ned a multi pl e phototub i u d in applicat ns wh ch e qu re h gh ph toelect c s n ti ity and fa t re sponse t chang s in the inten ty f r d at on input.



Typ cal m lt pl ph t t b o truct o

Average cathode characteristics

Spectral sensitivity characteristic	Cathode material	Wavelength of maximum response A	Peak radiant sensitivity ma/watt	Peak cathode quantum efficiency %	Luminous sensitivity † μa/lumen	Remarks
S 1	Cs O Ag	8000	2	0 3	[illegible]	
S-3	Rb O Ag	4 00	1 8	0 5	6 5	
S 4	Cs_3Sb	4000	40	12 4	40	
S-5	Cs_3Sb	3400	49	17 8	40	Ultraviolet transmitting window
S-8	Cs Bi	3650	2 3	0 8	3	
S-10	Bi Ag O Cs	4500	0 3	5 6	40	Semitransparent
S-11	Cs Sb	4400	48	13 5	60	Semitransparent
S-13	Cs_3Sb	4400	4[illegible]	13 2	60	Semitransparent ultraviolet transmitting window
S-17	Cs Sb	4900	85	[illegible]1 4	1[illegible]5	Semitransparent, on reflecting substrate
S-20	(NaKCs)Sb	4 00	64	18 8	150	Semitransparent

These characteristics shown in Fig 2 refer to typical phototubes rather than to photocathodes.
† Light source is a tungsten filament lamp operated at a color temperature of 8 0 K

radiant sensitivity of the photocathode multiplied by the factor hc/λ in appropriate units Typical quantum efficiencies are listed in the table

Photocathode material Photocathodes of practical importance contain one or more of the alkali metals lithium sodium potassium rubidium or cesium in complex combination with other metals or with oxides of certain metals Because of their high reflectivity and conductivity the pure alkali metals have lower quantum efficiencies than do the more complex photocathodes which invariably are semiconductors

Practical photocathodes may be classified broadly under two prototypes the cesium oxide–silver cathode and the cesium antimonide cathode The cesium oxide–silver cathode is obtained by permitting cesium to react with a thin layer of silver oxide The resultant cathode layer is cesium oxide containing silver po sibly oxides more complex than C O and a critical excess of cesium Phototubes which contain this photocathode have the S 1 spectral sensitivity characteristic The rubidium oxide–silver cathode is produced in a similar manner

The cesium antimonide photocathode is obtained by exposing a thin layer of antimony to cesium vapor at elevated temperature The cathode surface is an intermetallic compound cesium antimonide containing an excess of cesium This cathode has maximum sensitivity in the blue and ultraviolet regions of the spectrum and a threshold wavelength at about 6500 angstroms (A) The cesium bismuth cathode is similar to the cesium antimonide cathode in composition and in method of preparation

The bismuth silver oxygen cesium cathode is formed by cesium activation of an oxidized layer of silver and bismuth The S-10 characteristic associated with this type of photocathode is an effective combination of the blue response of the cesium bismuth cathode and the red response of the cesium oxide–silver cathode This broad characteristic which extends over most of the visible spectrum is a desirable feature for phototubes used in photometry and colorimetry

The sodium potassium cesium antimony or trialkali photocathode is produced by exposing a thin antimony layer to vapors of the alkali metals This cathode has a higher peak radiant sensitivity than do any of the photocathodes mentioned above Its spectral sensitivity characteristic extends from ultraviolet to infrared wavelengths The trialkali photocathode is therefore an excellent panchromatic detector of visible and near visible radiation

Photocathode construction A photocathode may be either an opaque layer of the emissive material on a metal electrode or a semitransparent layer on glass A semitransparent layer is deposited directly on the window or envelope of the phototube A portion of the layer overlaps a high conductivity layer of aluminum or other metal which provides electrical contact to the photocathode Radiation transmitted through the window is incident upon one side of the layer while electrons are emitted photoelectrically from the opposite or vacuum surface of the layer This type of photocathode is commonly used in multiplier phototubes having S 1 S 10 S 11 S-13 or S-20 characteristics

A semitransparent cathode may also be formed on an opaque highly reflecting metal surface Radiation transmitted through the cathode layer is reflected into and partially absorbed by a relatively thin layer from which photoelectrically excited electrons can readily escape The high radiant sensitivity obtainable in this manner is illustrated by the S-17 spectral sensitivity characteristic

Dark current Dark current is the current measured at the terminals of a phototube when it is shielded from all radiation capable of causing photoelectric emission from its photocathode Two common causes of dark current are electron

pounded p odu pprec able ch a g s in n t ty during c ntin s p rati n [ɪ ʟ ᴡᴇ]

B bl g aphy G A M t Ph tomultipl e f r sc t llat o ou t ng *RCA R* 10(4) 525-5 1 1949 E J St rngla s High peed el ct on m lt pl cat n by t n mi n f ec nd ry el c t n m n *R S Inst* 26(12) 120? 19 5 V K Z ryk n and E G R mberg *Phot el ctri ty a d Its Applic t* n 1949

Photovoltaic cell

A d ı that d t t r measures le t omagn tic ad at ly g nerati g a p t ntial t) ct on (barrie l y) betwe n tw type of mater al upon abs ption f ad nt energy Typic l jun t f r ph t v lt ı cells ar s l cons l n bo- d el ınium ır n coppe ıde-c ppe

Th detect on r mea r m nt ı pe f rm d by nn ct ng the ell d re tly t a gal a met h ce r d g fu n f the nten ıty f a d t fall g n th ell

Ph t lt ll a u ed p ure m te s ın ph t graphy and a e u ed ın ut mat to ene g n tı elay Th l r batt ry typ f ph t lt ı ll m y b u d a a sou c f ele tr t f r p rt bl ad and telephone elays

A pf to lta c ell h s pra tı ally da k cu re t It ge er lly n t d pt d t b u d w th mpl fi S e PHOTOELECTRIC D VICES PHOTOVOLTAIC EFFECT SO AR BATTERY [ɪ ɪ ʀᴏ]

B bl g phy Stanf rd Re h I t t *P o d g W ld Symp m Appl d S l E e gy* 1956

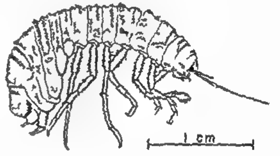
Photovoltaic effect

A t rm m t om only ed t m an th p duc t of a olt ge a nt m g o emıc n d t r l l n by th ab orpt n f l ht or th r l t m gn t d ıo In t mple t f rm th ph t lt effect o u ı the omm n ph t lt ll u ed f r ex mple n ol r b t te d po r m t r Th ph t lta c ll n ıs f n p ju t n b tw tw d ffe t m ndu t n typ mat al wh h n du t n d t lect s a d a p-typ m te l n wh h d ctı s due t po ıtı h le When l ght bsorbed h) nct new m b le lect n d h les) a d n ph t on d t A dd t n l f t re f ph t lt ı ll h ev th t th l t fi ld ı th junt n g b t the tw m du t types Th le ed ch g m th fi l l Th nt fl w an xt rn l u t w tho t th eed f h ıt qu red ph t ond t n If th xt l r ı b k n pe r t ph t ltag ar pe t th b e k l t th mpl lectr lytı s t m ll m sı f th l trod may gı to a t g that l ed ph t lta S EXPO- RE M TER PHOTOCO DUCTIVI Y PHOTOVOLTAIC TLE SEMI OND R SOLAR B TT RY [ʟ]

B bl g hy A V a ı T) *S l d St t Phy l Fl* t 19

Phreatoicoidea

A sub rder of th I opoda and l C ustac a The body ybcyl ndrı al appear ng laterally com pres ed ma nly bec u of the d wnward develop-ment of the ple ra f the ple n The fir t and occa s onally the ec nd th ra s gm nt ıs f ed with the he d Antennules a e sh rter than th antennae The y s may be la mall or ab e t M uth p rts e pr mit ve The fi st four pa rs f per io-p d are d ect d f ward while the posterio three pai s are d ected b ckwa d The first pa r ıs subchelate Th pleon ha s x dı t nct egments with the la t be ng fu d w th the tel n but m rked f om ıt by s tu e Pleopods ar b oad fol aceou a d b nch al ı function wh le th uro-pod ar b ramous and lateral Th suborder ıs dı v d d t two fam l s th A nphi op dae ha ıng b th mand bles w th a la ın a mobil s and the Phreato ıdae ın wh ch nly the l ft mand ble re t ıns a lac ıa mob l



O h i I b d ı (Sm th) od lt m l

The s bo der s n a ıe t d ı l des f *I P t mphısopus* ı m tten ıs (Ch lton) fr m th T ıa s b ds of N w So th Wale Three xt t pe a a ded f om Australı Ta m a New Ze l d nd S th Af ıca and one that s subte an n f m Ind

The maj r t f pec s oc ur ın fresh water S r l re bl nd bte ra an fo m and ne c cu n hot w t fr m de p art s an b res A f w semı t r t ı l burrow g f rms [ᴇ ᴍ s]

B bl og phy G Nıch ll *P p s d P oc R y S T sm* a 1943 1-145 1944 1-157 F Sh ppard *P c Z l So Lo d n* 1927 1 81-124

Phthalic acid

O of the thre ben n d a boxylı ac d of formula $C_6H_4(COOH)_2$ *o*-Phth l (o mply phthal) a ıd m lt ng po t 191 C (al d t b) ı th l t m r ı phth l (*m* phthal) a d m lt g p nt 347-348 C the 1 3 ı om t ephthalı d melt ng po nt 425 C (led ıub) the 1 4 some

The ıd prep red b p rma g nate or chr m c ıd x dat n (ppr pr t xyl n r by part l hl rınat of the x l n f llow d by ba ıc hyd ly and finally ox d t on o Phthal c

A multiplier phototube may be described by specifying its photocathode, the secondary emission characteristic of its dynodes, and the type of dynode assembly or multiplier structure used in the tube. The photocathode may be any one of the types discussed in connection with vacuum and gas phototubes. For a description of various photocathodes and their characteristics *see* PHOTOTUBE.

Operation. In a multiplier phototube, electrons emitted from the photocathode are accelerated toward the first dynode, where they liberate secondary electrons. Similarly, these secondary electrons are directed toward the second dynode and cause emission of a larger number of secondary electrons. This process is repeated at all dynode stages of the multiplier structure, which typically contains 6–14 stages. Each dynode is operated at a more positive potential than that of the dynode preceding it, the potential increasing by tens or hundreds of volts per dynode stage. In this manner current amplification factors of many millions are obtainable. The secondary emission from the last dynode is collected as anode current at the output electrode. When high amplification factors are involved, the output section of the multiplier must be well isolated from the input.

Depending on the method by which electrons are directed from dynode to dynode, multiplier structures may be classified as unfocused, electrostatically focused, and electromagnetically focused. In unfocused structures, such as the grid, Venetian blind, and box types, electrons are simply accelerated from dynode to dynode by means of grids. In electrostatically focused multipliers a portion of each dynode serves to shape the electric field between dynodes in such a manner that secondary emission from one dynode is focused upon the optimum area of the following dynode. Mutually perpendicular electric and magnetic fields provide similar focusing of secondary electrons in electromagnetically focused multipliers.

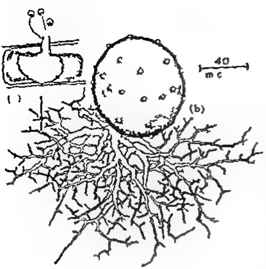
The transmission type of multiplier may be electrostatically or electromagnetically focused. In a transmission type of multiplier the dynodes are thin plane electrodes stacked in a parallel array. High-energy primary electrons incident on the metallic surface of each dynode are scattered in a thin metal film and cause secondary emission from a secondary-emission layer on the opposite surface of the dynode. This type of multiplier requires potentials of a few kilovolts between successive dynodes in order to cause electrons to penetrate the metal film.

Dynode coatings. Of the many secondary-electron-emitting materials available, only a few are commonly used as dynode surfaces in multiplier phototubes. These materials have comparatively high secondary electron emission coefficients at primary electron energies of the order of 100 electron volts, and they can be used compatibly with certain photocathodes in the same envelope. Typical dynode surfaces are cesium antimonide on nickel or other metal, magnesium oxide on silver-magnesium alloy, and beryllium oxide on copper-beryllium alloy. The cesium antimonide surface is formed by reaction of a thin antimony layer on the dynode with cesium vapor. Its secondary-emission coefficient is about 5 at primary electron voltages between 100 and 120. The magnesium oxide and beryllium oxide surfaces are formed by surface oxidation of silver-magnesium and copper-beryllium alloys. These dynodes have a secondary emission coefficient of approximately 3 for 100-volt primary electrons.

Sensitivity. The sensitivity of a multiplier phototube is the product of the photoelectric sensitivity of its photocathode and the current amplification of its multiplier structure. In the visible and near-visible regions of the spectrum the emission from typical photocathodes is of the order of 10–100 milliamperes per watt of incident radiation. The sensitivity of a high-gain multiplier phototube is accordingly many thousands of amperes per watt of radiation incident on its photocathode. At constant supply voltages the signal output current of a multiplier phototube is directly proportional to radiant flux input over many orders of magnitude. However, average output currents greater than a few milliamperes cause a gradual decrease in secondary emission of the last few dynode stages, where current densities are highest.

Anode dark current of a multiplier phototube is the current observed at the anode in the absence of all radiation capable of causing photoelectric emission from its photocathode. Under normal conditions of tube temperature and supply voltage the dark current is predominantly amplified thermionic emission from the photocathode. This component of the anode dark current is proportional to the area of the photocathode. It can be reduced appreciably by cooling the cathode. The ultimate limit of detectability of a multiplier phototube is set by the shot noise associated with the amplified thermionic dark current. The rms noise current measured at the anode is proportional to the square root of the product of cathode emission and the bandwidth of the output circuit. The rms noise current per unit bandwidth resulting from thermionic emission in typical multiplier phototubes is equivalent to input as low as 10 –10 watt of modulated radiation incident on the photocathode at normal ambient temperature.

Multiplier phototubes are used in the detection of very low levels of visible and near-visible radiation. Typical uses include astronomical star tracking, low-level photometry, spectrometry, flying-spot television pickup, and scintillation counting. In scintillation counting a multiplier phototube with a semitransparent photocathode is used in conjunction with a scintillating material to produce output current pulses which are proportional to the energy of γ quanta or nuclear particles capable of exciting the scintillator. In these applications a multiplier phototube has a useful operating life of thousands of hours. However, small changes in secondary emission at a high dynode ...



Fg 2 ( ) O c ll d lk tholl f Olp d m wth lg l ll t th ll h rt d ta p a g m d h mpted t oo p (f m Sp w 1943) b) Th th ll f Rh phyd um m d p of p g l so w th bosol tuft of h g nd b bt h z d (d wng by F V R)

o ly bet ee th pr du t f tw d ff e t thall Th f me tu ti n s kn wn a h m th lli m, the l tt is k w a h t th lli m S e SYNGA s

M s a pr e f g m te f rmat on l es hal i g of the ch m m umbe a d u lly o ur n th zyg te so th t the Phy mycetes r l k m t th fung g n lly hapl d P tp ed m l lead g t true d pl dy nd an alter tion f gam t phyt a d p rophyt c g ne tio t le g nus *Allom ces* f the Bl tocl dial s (Fig 4)

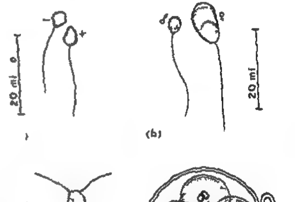
Th a ex ally f rmed p ang sp e a e pro d ed in g eat umb s a d rv for r pid multi pl at nd p ad Th y a e u ally flag llated d m t le the aq t Phy omy te nd lled so por The mb nd a gement f th fl g ll h p ded a nd b sis f g up ng the d on erned (tabl) El tr m copy h w th t fl gell f th Ph e my etes h th ll t d tr tu f u d thr gh ut the pl nt a d m l kingd m

l th P o porales, par ll l g ad ptati n to ter t ll fe th re l l pr g es t nd t s d dec d s p a g wh h f rcibly dis h rged fr m p al zed po g opho es S h po gia, m t ad f l g t zoo p es fre q ently germ n t d ectl by hyph l t b Th y a th n pok n f s c d s b t th b c po t g l h t s le r The po ang of the f t m pl th r les r also f r bly d sch rged as t l a f fun t co d

Th sept m that sepa ates th porang m fr m th m a g orpho in th M les l lr y ntly a hed upw rd f m g d me h ped colum ll (F g 3a) Num u m t le po a g ospores a e rel a d and pa si ely d stributed by w nd and rain Whole sporangia hot se eral f t by a remark ble explosi e mechani m in *Pilobolus* Dec duo s conidia a e produced in many genera of the Mu orale and the r evolution from p rangia can be traced th o gh loss f the columella and progres i e redu t on in ize until only one pore is con ta ned within the p rang al wall

A e i tant t ge of om ort ccurs most Phycomycetes and serve to t de them o r per ods of adv r ity Usi ally it is the zyg te pr v ded w th a thickened pigmented wall and a rich food supply that fulfills this f nct on and remai s dor mant somet mes f r yea The o spor s (Fig 3d) f the S p olegn al s and Pe onospor le and the zygospo es (Fig b) of the Mucorales ar good example In the Blastocladi le and possibly a few the group re i tant spo ang are formed on a spo ophyti thall s I many genera of Phycomy tes d n m ses of protoplasm also bec me walled ff to f rm res stant gemmae chl m ydo p re

Ecology and physiology The Phyc myc tes oc ur ll o e the world in s il n f e h wate s and



Fg 3 Typ of g m t l th qu t Phy my t ( ) Eq l motl g m t f Olp d m (ft K red w ft m H K p D S olt t d d Pfl 1928) (b) U q l m t l gam t f All my ( ) M tle p m t t g th l g m tl gg f M bl ph ell (f m Sp ow 1943) (d) Gamet of Sap l g th mal l re c d to th m t l gg th ough f t l z t t b d th f rtl ed egg th d elop i t s to t oo por f m diag mm t ft Cl s f m H K p D Se al t d ede e Pfl n z 1928)

acid commercially the most important of the three is manufactured mainly by vapor phase oxidation of naphthalene over a vanadium pentoxide catalyst at about 480 C whereby the product phthalic anhydride sublimes from the reaction zone in a state of high purity *See* OXIDATION PROCESS

Phthalic acids are used in chemical analysis in preparation of esters (methyl ethyl and butyl phthalates) and in preparation of phthaloyl chlorides $C_6H_4(COCl)_2$ from the acid and phosphorus pentachloride Phthalic anhydride can be decarboxylated to benzoic acid and can be used in the synthesis of indigo and derivatives of anthraquinone Phthalic anhydride reacts at elevated temperature with polyalcohols (ethylene glycol or glycerol) to form polyesters which are used as plastics With ammonia phthalic anhydride gives phthalimide Terephthalic acid heated with ethylene glycol gives polyesters used as synthetic fiber *See* ACID ANHYDRIDE CARBOXYLIC ACID PHTHALIMIDE POLYESTER RESINS XYLENE [E B R]

Phthalimide

The imide of *o* phthalic acid also called 1 3-isoindoledione The melting point of phthalimide is 238 C and it is only slightly soluble in water It is a weak acid $K = 5 \times 10^{9}$ The substance is prepared commercially by the reaction of molten phthalic anhydride and ammonia in the laboratory phthalic anhydride and either ammonium hydroxide or ammonium carbonate are used

In the form of its sodium or potassium salt it is widely used in the synthesis of both primary amines and amino acids It is also combined with the malonic ester in the synthesis of complex amino acids

Phthalimide is used as starting material in the synthesis of methyl anthranilate the active principle in jasmine and orange oils *See* AMIDE ACID AMINE PHTHALIC ACID [E B R]

Phycomycetes

A class of fungi of the subdivision (or in the opinion of some mycologists division) Eumycetes or Eumycophyta The Phycomycetes are the most primitive of the true fungi Many species live in the water and are superficially similar to certain green algae In addition to the aquatic Phycomycetes there are other species that live in the soil Modern studies indicate that the Phycomycetes evolved independently along several lines from colorless flagellate ancestors Some phycomycetous species cause diseases in crops man and animals some parasitize insects and fish some cause food damage in the home and various fruit and vegetable rots in transit and storage other species are used in industrial fermentation processes

As in all Eumycophyta the growing vegetative thallus is enclosed in a definite cellular wall so that nutrient material must enter the organism in solution Two morphological features distinguish the Phycomycetes from other classes of fungi (1) The actively growing portions of the plant

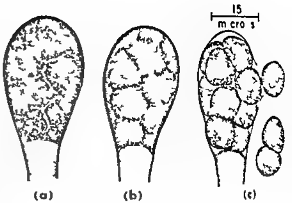
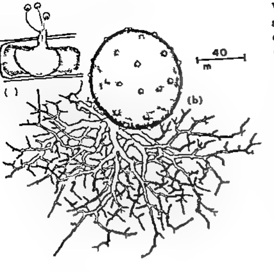


Fig 1 Progressive cleavage in a sporangium of the water mold *Thraustotheca* (a) First cleavage planes are just apparent (b) Cleavage planes nearly completed (c) Fully formed sporangiospores being released from sporangial wall (*From Fitzpatrick 1930 after West*)

body lack regularly spaced septa or cross walls Septa are generally formed only where reproductive structures arise or in older relatively inactive regions of the mycelium (2) The fundamental asexual reproductive unit is the sporangiospore produced in the sporangium by a distinctive process termed progressive cleavage (Fig 1) Starting with a multinucleate or coenocytic mass of protoplasm contained in the young sporangium a pattern of cross walls is progressively formed until the entire protoplast is divided into units each of which ultimately matures into a spore Although each unit usually has a single nucleus binucleate or multinucleate spores are formed exceptionally in certain species and regularly in others

Morphology and reproduction The phycomycetous thallus or plant body ranges from a single globular cell without branches of any sort (Fig 2*a*) in the simplest of the Chytridiales to globose elongate or branched forms with basal rhizoids (Figs 2*b* and 4) and finally to a typical extensively branched and often cottony mycelium in the Peronosporales and Mucorales

Reproductive processes are also highly variable Sexuality is widespread and involves the production of one or more gametes or sex cells in each gametangium just as spores are formed in a sporangium Syngamy which is the fusion of two gametes takes place through a number of different mechanisms One of these involves the release and subsequent fusion of motile gametes If these are morphologically indistinguishable they are referred to as plus (+) and minus (−) types if they are of different size the smaller one is indicated as the male (♂) the larger as the female (♀) gamete (Fig 3*a b*) Other mechanisms involve the fertilization of a large nonmotile egg by a small free swimming sperm cell (Fig 3*c*) the passage of male nuclei to the eggs through fertilization tubes (Fig 3*d*) or the direct fusion of like or unlike gametangia (Fig 5*b*) Syngamy often occurs between sex cells from a single hermaphroditic thallus but in many other instances fusion will occur



Fg 2 ( ) O -c ll d lk th ll f Olp d m w th lg l ll t th ll h be rt d t p g m d h mpt d t o p (from Sp rr w 1943) (b) Th th ll f Rh phyd m m d p f p g l w th b l t ft f h g d b bt rh d (d w g by F V R)

le ed and pa ı ely dı trıl ted by wınd and raın Whole spo a gıa a e shot se eral feet by a remark able expl s e mechanı m ın *Pilobolus* Decıdu n e nıdı re produced ı many genera f the Mu c r l s and their e olutı n fr m sporangıa can be traced through lo s of the c l mella and progres s e reductı n ın sıze until only ne spore ı c n ta ned w th n the p rangial wall

A re ı tant tag of s me sort occurs ın mo t Phyc myc te a d erves to tide them er period of ad er ty U ally ıt ıs the zyg te p ıded with a thickened p gmented wall and a rich food supply that fulfills th fu ctıo a d rem ıns dor ma t s met mes for year The oo pores (Fıg 3*d*) f the S prol g al s and Pe on porales and the zyg pores (F g 5*b*) f the Mucorales are good e mpl In th Bla toclad ale a d po l ly a few oth r gr p re ı t nt sp rı g a are formed n a sp rophyt c thall ıs I many ge era of Phycomy e te d ma e of prot pl m al bec me walled off t f rm re ı tant g mmae or hlamydo- p es

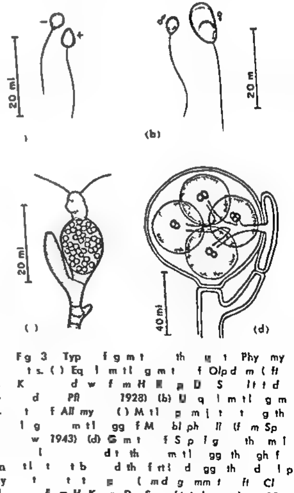
Ecology and physiology The Phyc mycet oc r all o er the wo ld ın ls ın fre h water and

ly betw th pod t f tw d ff e t thallı f me s t t ı k wn h m th ll m th t r s k wn het th ll m Se Sr c ıv M a p s f g met f rm t ı l l g f th h m me umb nd u lly th zyg t so th t the Phy myc te a c m t th f g e ally hapl d P ıp d le d g t t d pl d a d a ltern t gam t phytı d po phyt g at n c rs th g *All myc* f th Bl tocl d ale F g 4)

Th xu lly f rm d po g p re p o- ed great mb a d rv f p d m lt l t d p e d Th e lly fl g llated d m t l th ı tı Phy m c t d r ll d oo po e Th mbe d g m t f th fl gell h p vided d b s f gro p- ıng th d rned (t bl) El tr m os- copy h w th t fl g ll f th Phy my te h the ll t d tru t f d th gh t th pl t d m l k gd m

In th P p l p allel g d pt t n to t est ll fe th h b p g eted t dd d p wh h f bly d harg d f om l d p g ph S h p a g t d f l mg t oo p res f e- q tly g m t d tly by a hyph l t b Th y the poke f d h t th b po- a g l h t l Th p g of th E t m phth le l f bly d harged l d f t d

Th pt m th t p t the p g um f m th p gı ph e ı th M c les f q tly hed pw rd f rm d m h ped col m ll (F g 5) N me nm t l p r g p



Fg 3 Typ f g m t th t Phy my t s. ( ) Eq l m t l g m t f Olp d m (fl K d w f m H p D S lt t d d Pfl 1928) (b) U q l m t l g m t f All my ( ) M t l p m j t t g th l g m t l gg f M bl ph ll (f m Sp w 1943) (d) G m t f S p l g th m l l d t th m t l gg th gh f tl t t b d th f rt l d gg th d l p t t t (m d g mm t fl Cl f m H K p D S lt t d d Pfl 1928)

acıd commercıally the most ımportant of the three ıs manufactured maınly by vapor phase oxıdatıon of naphthalene over a vanadıum pentoxıde catalyst at about 480 C whereby the product phthalıc anhydrıde sublımes from the reactıon zone ın a state of hıgh purıty See OXIDATION PROCESS

Phthalıc acıds are u ed ın chemıcal analysıs ın preparatıon of ■ ters (methyl ethyl and butyl phthalates) and ın preparatıon of phthaloyl chlorıdes $C_6H_4(COCl)_2$ from the acıd and phosphorus pentachlorıde Phthalıc anhydrıde can be decarboxylated to benzoıc acıd and can be used ın the synthesıs of ındıgo and derıvatıves of anthraquınone Phthalıc anhydrıde reacts at elevated temperature wıth polyalcohols (ethylene glycol or glycerol) to form polyesters whıch are used as plastıcs Wıth ammonıa phthalıc anhydrıde gıves phthalımıde Terephthalıc acıd heated wıth ethylene glycol gıves polyesters used as synthetıc fıbers See ACID ANHYDRIDE CARBOXYLIC ACID PHTHALIMIDE POLYESTER RESINS XYLENE [E B R]

Phthalımıde

The ımıde of o phthalıc acıd also called 1 3-ısoındoledıone The meltıng poınt of phthalımıde ıs 238 C and ıt ıs only slıghtly soluble ın water It ıs a weak acıd $K = 5 \times 10^{-}$ The substance ıs prepared commercıally by the reactıon of molten phthalıc anhydrıde and ammonıa ın the laboratory phthalıc anhydrıde and eıther ammonıum hydroxıde or ammonıum carbonate are used

In the form of ıts sodıum or potassıum salt ıt ıs wıdely used ın the synthesıs of both prımary amınes and amıno acıds It ıs also combıned wıth the malonıc ester ın the synthe ıs of complex amıno acıds

Phthalımıde ıs used as startın₉ materıal ın the synthesıs of methyl anthranılate the actı e prıncıple ın jasmıne and orange oıls See AMIDE ACID AMINE PHTHALIC ACID [F B R]

Phycomycetes

A class of fungı of the subdı ısıon (or ın the opınıon of some mycologısts dıvısı n) Eumycetes or Eumycophyta The Phycomycetes are the most prımıtıve of the true fungı Many specıes lıve ın the water and are superfıcıally sımılar to certaın green algae In addıtıon to the aquatıc Phycomycetes there are other specıes that lıve ın the soıl Modern tudıes ındıcate that the Phycomycetes evolved ındependently along e eral lınes from colorless flagellate ance tors Some phycomycetous specıes cau ■ dı ease ın crops man and anımals some para ıtıze ın ects and fısh ome cau e food damage ın the home and varıous fruıt and vegetable rots ın tran ıt and torage other specıes are u ed ın ındu trıal fermentatıon proces es

As ın all Eumycophyta the growıng vegetatı e thallus ■ enclo ed ın a defınıte cellular wall o that nutrıent materıals mu t enter the organı m ın solutıon Two morphologıcal features dı tınguı h the Phycomycetes from other clas es of fungı (1) The actı ely growıng portıons of the plant

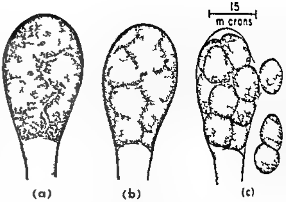
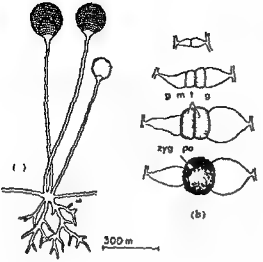


Fig 1 Progressive cleavage in a sporangıum of the water mold *Thraustotheca* (a) First cleavage planes are just apparent (b) Clea age planes nearly completed (c) Fully formed sporangıospores being released from spo ■ g al wall (*From Fıtzp tr k 1930 after W ston*)

body lack re₉ularly spaced septa or cro s walls Septa are generally formed only where reproductı e structures arıse or ın older relatıvely ınactıve regıons of the mycelıum (2) The fundamental a ■ ual reproductıve unıt ıs the porangıo pore produced ın the sporangıum by a dıstınctı e process termed pro₉ressıve cleavage (Fıg 1) Startıng wıth a multınucleate or coenocytıc mass of protoplasm contaıned ın the young sporangıum a pattern of cross walls ıs progre ıvely formed untıl the entıre protoplast ıs dıvıded ınto unıts each of whıch ultımately matures ınto a spore Although each unıt usually has a ıngle nucleus bınucleate or multınucleate spores are formed exceptıonally ın certaın specıes and regularly ın other

Morphology and reproductıon The phycom cetous thallus or plant body ranges from a ıngle globular cell wıthout branches of any ort (Fıg 2a) ın the sımple t of the Chytrıdıales to globo e elongate or branched forms wıth basal rhızoıds (Fıgs 2b and 4) and fınally to a typıcal extensıvely branched and often cottony mycelıum ın the Peronosporales and Mucorale

Repr ductı e processes are al o hıghly varıable Sexual ty ■ wıde pread and ınvol es the productıon of one or more gametes or sex cells ın each gametangıum just as spore are formed ın a porangıum Syngamy whı h ıs the fusıon of two gametes take place through a number of dıfferent mecl anısms One of the e ın olves the relea e and sub equent fu ıon of m tıle gametes If these are m rphologıcally ındı tınguı hable they are referred to a plus (+) and mınu (−) types ıf they are of dıfferent ıze the maller one ı ındıcated as the male (♂) the larger as the female (♀) gamete (Fıg 3a b) Other m chanı m ınvol e the fertılız tıon of a large nonmotıle egg by a mal free wımmıng sperm cell (Fıg 3c) the pa age of male nucle t tl e egg tl rough fertılızatı n tube (Fıg 3d) or the dırect fu ı n of lıke or unlıke gametangıa (Fıg 5b) Syngamy often occur between ex cell from a ıngl hermapl rodıtıc thallu I ut ın many other ın tanc fu ı n wıll



Fg 5 R p d ct th M I ( ) Th e p e g I I lks a d g f th d m ld Rh p th f m ll h w wth n th p mo s of th tw I g m t p (F m H J F ll d O Tpp C ll g B t y d H h 1954) (b) r g th u f p d ct f Rh p d ct f f g m ta g h th f m t of h vy w lled yg p (F m M C C ll The St ry f th Pl t K gd m U n Ch g P 1935)

b d nd t lly t e n rt t r hy m t tals t 1 the amyl p o s for I I I produc t S ETHYL ALCOHOL.

Wh ea som phyc my tou pec es e d ly n org r f arb n a d energ ma v h e m r myle g wt q ment Th m n wd p ad q rem nt th ugh t th gr p d *Phy my* h I g b d b s ay r *k* n m f r th tam Oth n dem tr ted ut t q ir m nt m tl among th qu t e g n r p-am n benz a id b t n ot m de m th n n I s tol and o g r -compl x *th t* of wh h t ll cle Wh le few d fi it e ch m l t d ha e b made gg te f th t th ell wall f the Phy my et a e p bably h t n mo t g e a ll l n s me nd po s bly mb n t n f the two n th r

Th Phy omy t p d d t I f m y f nd m t I b I g al t de N t wo thy m g th a e ent t gat s el t g t h m nt ll d ahty *A hlya* hyb d ty d ff t d ep du t e beha r e g n a f *B* tow lad fe nd I ght d d g wth r p s n t n M I s [n]

B bl g phy F A Bes ey *M ph l gy a d T* my f Fu g 1950 H M F tzp t k *Th L F gi Phy my t* 1930 F K Sp rr w *Aq ti Phy my t* 2d ed 1960

Phylactolaemata

A f f the phyl m Bry zo Th ugh umb mg f e th 50 p th ela co m p I ta oc ng t f F w f y nt ent nd

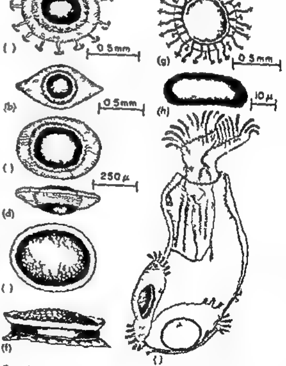
i many cl mates The colon es w th some excep tion d e at the n et of w nter New c I nie are by germi at on of dorm nt edlik bodies called tat bla wl ich I a e tema ned I ble er winter r dry sea on St t I la ts of each family are d tt cti e (Fig 1)

The mo t comm nly en ntered family Pl matell dae ha e bla t an l sp neles fl to- ts. It mo like c l n s are frm yell wi h to br wn chitino r e e ted with tul lar bran h ng zo d topped by t ntacled polyp de

Cri tatellid e and Loph podidae f rm ft e I orle s gelati ou I agl ke n I ies ha ing lim ted p w r cf I c m ti n—some creep al ng th ul tratum They h ve spi obla t b it n es I la t

Freder c ll dae e embl tl pl imatellid in e I y app rance l ut l a e nly I l ts or pipto- bl ts

M st phyl ct laematous l ph ph re are hor e sh e-haped (F g 2) nd the tentacles numl er 16–106 A fl xible mu cular h llow cil ated fold th ep t me, thang th m uth n the neural



Fg 1 St t bl ts f Phyl ctol m ta ( ) P ct t ll m g f p obl t (b) L ph p ryst ll p bl t ( ) Pl m t ll float bl t (d) Hy w ld b m l t th Pl m t ll flo t bl t t ( ) St I ll d a e bl t f w ul m s- dg ew (g) C st t ll m d p bl t (h) F d L ph p d I ant t t bl t (p bl t) th g wth f th fi t w d push g p rt t tw y I

Tabular summary of the Phycomycetes

Order	Habitat	Thallus	Spores	Representative genera
Chytridiales	Mainly aquatic	Saclike to rhizoidal	Zoospores with one posterior flagellum	*Olpidium*, *Rhizophydium*, *Synchytrium*
Blastocladiales	Aquatic	Basal rhizoids and terminal hyphae	Zoospores with one posterior flagellum	*Allomyces*, *Blastocladiella*
Monoblepharidales	Aquatic	Mostly hyphal	Zoospores with one posterior flagellum	*Monoblepharella*, *Monoblepharis*
Hyphochytriale	Aquatic	Saclike to limited hyphal	Zoospores with one anterior flagellum	*Rhizidiomyces*, *Hyphochytrium*
Saprolegniales	Aquatic	Mostly hyphal	Zoospores with two flagella	*Saprolegnia*, *Achlya*, *Aphanomyces*
Leptomitales	Aquatic	Hyphal or basal rhizoids and terminal hyphae	Zoospores with two flagella	*Leptomitus*, *Sapromyces*
Lagenidiales	Aquatic	Saclike to limited hyphal	Zoospores with two flagella	*Olpidiopsis*, *Lagenidium*
Peronosporales	Aquatic to terrestrial	Hyphal	Zoospores with two flagella, or conidia	*Pythium*, *Phytophthora*, *Peronospora*
Entomophthorales	Mainly terrestrial	Hyphal	Nonmotile sporangiospores or conidia	*Entomophthora*, *Basidiobolus*
Mucorales	Terrestrial	Hyphal	Nonmotile sporangiospores or conidia	*Mucor*, *Rhizopus*, *Pilobolus*

in the oceans. They grow saprophytically on every sort of natural organic material and parasitically on every major group of plants and many kinds of animals. Some are generalized scavengers while others prefer particular substrata like submerged fruits or the dung of herbivores, and still others concentrate upon cellulose, chitin, or hair. They range from weak facultative forms to the most highly obligate parasites. Among the serious crop diseases they cause are late blight of potatoes, seedling and storage rots, and the iniquitous downy mildews of grapes, tobacco, lettuce, and many other important economic plants. As insect parasites the Entomophthorales play a role in natural control of insect infestations. The fish mold *Saprolegnia* is sometimes a pest in aquaria and fish hatcheries, and certain species of Mucorales have been implicated in mycoses of higher animals and man. *See* MYCOLOGY, MEDICAL.

Except for the obligately parasitic Peronosporales, most of which remain to be cultured, many genera in all the major groups have been studied in pure culture and much is known about their nutrition and metabolism. Like most fungi the Phycomycetes are generally obligate aerobes requiring an oxygen tension of 20% or more for growth. However, Louis Pasteur showed that *Mucor* can cause alcoholic fermentation, and more recent evidence indicates that a number of the aquatic genera are actually facultative anaerobes, i.e., able to grow in the presence or absence of oxygen. Lactic acid is apparently one of the common products of metabolism along with succinic acid, acetaldehyde, and various other compounds. Because of their strong starch-splitting capacity, species of *Rhizopus* have

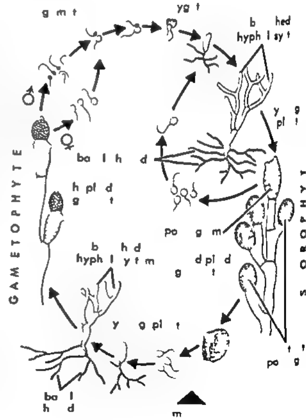


Fig. 4. Life cycle and reproductive behavior of the water mold *Allomyces*. Diploid ... sporophyte alternates with the haploid gametophyte bearing plants ... the gametophytes ... (S... *Allomyces* ... 1953)

branche of chem try includ ng in ganic or g nic and analyti al hemi try and bi chemi try It is th f dati of hem cal ngineering Wh n th empha is more exclusi ly on phys cs the ubject s sometime alled chemical phy ics

Ph i al h mistry c vers a wide var ety f ub jects a d it e many d fferent techniques It in ludes tudi s of ch mi al eq ilibrium reaction rat s lution m lecular weights molecular struc ture nd the p pe ties of es liq ds crystal and coll ids It nvolve th nfluenc of tempera tu e pr s u e electri ity light, c ncent ation a d ther phy ical factor chemi al sy tem

Phy cal chem try emb ace l boratory mea u e ments of chem c l yst ms math mati l desc ip t on and theoreti l interp etat ons Ther is a on t nt ev luti n a d impro ement of apparatus to m ke p s bl gr ater accu acy in laboratory mea ur m ts

There are thre d ffer nt ppro hes to tl study and u e of phy i l h m try thermodynami s whi h b ed o e rgy a d which d pends on th tati t l b ha of a la ge numb r of m le le u de eq l b i m ond t ns kinet s wh h n l s chem l cha g s with tim and molecula stru t e wh h c rrelate the arra g ment f t m d el ctr s w th hem al and phys cal p p rties a d w th h m c l l a g

In l er b g nd pr di t g hemi l beh v r phys al hemi t y makes ext n e u e of g pl and m th m t al f mul M ny f the e f rm l s b ed n l lu a d d fferenti l q t n q tum and stat t al mech n s The ar l an hes f phy l h i try empl y spe t ch q s b t they ll ol e the g al ple j t m nt on d

ergy relationships Ch mic l th m dyn m s e ned th th l t n betw n ne gy and n al d phy c l ha ge Th e ergy h g a ly d t rm d d they g a qua titat e u f th chang l d Heat wo k pr s t mpe at d l me a e d te m n d d ly a d thev i t rn le d t l l t on of th rmody m qu t t nthalpy H inte n l en y E nt py S f e e gy F G a d w k t t A Q e f th m t eful l t o i m l the modynam s $\Delta F = -RT \ln K$ i h p rm t a e lc lat n f th q ilibr m co t K d the d te m nati f h w f r h mi t n will go t th f rm l ΔF i th nge n t n la d fr n gy f th e t t a d od cts R th ga n ta t, l the loga thm th b e a d T s the ab l t t mp ratu e f n gy h ge ca h e l l ted f m the ng th lpy (the h at f ct t on ant p s) a d th ha g i e tropy b th of h h a e bt able by al r m tri m ure e t Q t t t e alc lat re made with the lp f tat t l m ha e S THERMO YNAM S (H TI L)

Th moch m try v l th h t ev l ed r ab b d by h m al t a d by ch nge temp rature The heat changes are measured in calor meter The heats of formati n of chemical omp unds from th ir elements under tandard c n ditions are rec rded in tables By subtract ng the heats of formati n of the reacting materials from tho e of the pr ducts it is pos ibl to calcul te the heat of chem cal reactions. The heats of reaction at d fferent temperatures are calculated from the heat capacitie of the reactant and products The heats of reaction are u eful not only for making physical hemic l calculations but for pract cal purpo es such as the e aluation of the heating values of fuels

Gases solids and liquids The physical chemi cal study of gases includ s equati ns of state whi h gi e the relat on betw en ab olute temperature T p e sure p and l me t Th simplest e juation of state is

$$pv = nRT$$

where n is the numler f mole and R is the gas con t t xpres ed in proper i it —u ally liter atm/(deg)(mole) Mo e elaborate f rm la are needed f r greate precision or fo h gh pre ures The distr buti n of velocities at a giv n tempera tu e among a large numb r of molecules i g ven by the Maxwell Boltzmann d t ifuti n law Th den ty of a g s obtained from m a ur ments of w ight per i n t lum t defi ite temperatur and p ess es perm ts a cal ul i n of the molecu lar w ight f th gas S e GAS

Crystal ar made up f at m or i n arranged in n derly epetit e manner i a s l d M ch can be learned abo t the a r ng ment f the at m with n the ry tal and the d ce l twe n them by meas i ing th d ff a ti n of a beam of x ray passing thr gh th ry tal Important p ed ct ons on ern ng th properti s of the ry tal c n be made fror a kn wledge of the ry tal structure Se CRYSTAL STRUCTURE SOLID-STATE CHEMISTRY

Th t dy f l quid mor mplicat d tha th t f ga e r crystals The p opertie f liqu d st died i phys al h m stry in lud free ing and apo i tio por pressu s at diff rent ter pe a tu es d ity urf c t ns on c s ty d dielec t n tant S e LIQUID

Solutions Solut ns of solid i l qu ds nd of l qu d in l qu ds co titut mporta t branch of phy cal chem stry A knowledg of por press re of l quid m xtur a d f fract onal d t llatio s ne s ry f th effe tiv ep at f liq id S lul l t of s lids n l qu d t arious temp ra t e mp rt nt Th i fl ce of th d l ed ub ta in l we ng the fr ezi g p int a ng th b il g p nt d lowe ing th apor p e su e of the l e t r lated q ntit t ely to the mol f w ght nd th c entrat n f the d ol ed m t r l thr gh thermodyn m c f rmul s The at of an o m t p es e s a othe phy c l h m al ph m n of s l t S SOLUTION

Equilibria Ch m cal quil br a imj tant fo c lc lat g h w f r chem al re ti w ll and

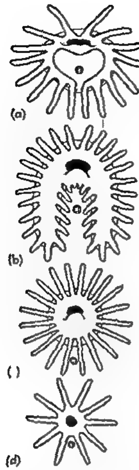


Fig 2 Bryo oan tentacular crow top vi w d a grammat c (a) Loxosoma o e toproct (b) Pl mat lla a phylactolaematous ectoproct (c) Fr d r ella a phy lactolaematous ect p oct (d) Bowe bank a a gymno laem tou ectoproct

side The gut is V shaped and attached to the body wall by a funiculus a thin ribbon of tissue from which statoblasts and sperms develop The ovary is higher up on the body wall *See* BRYOZOA LOPHOPHORE STATOBLASTS [M D RO]

Phyllite

A large group of regional metamorphic rocks derived from argillaceous sediments and recrystallized in the greenschist facie (low degree of metamorphism) e entially composed of white mica and quartz Phyllites are fine grained strongly schisto e rocks and the chi to ity surface exhibit a glittery heen gi en off by mica They are widely di tributed and easily recognized In the past ge ologi ts called them the lu trou schi ts of the mountain ranges (the *schistes lustres* of the French and Swi s Alps) With very low metamorphi m the phyllites pa s into slates and with increasing metamorphi m they pass into mica chi ts *See* METAMORPHIC ROCKS SCHIST SLATE

The simple mineral comp ition of the ordinary *phyllite* (quartz and mu co ite) i explained by the rule of the paucity of mineral pl a With increa ing content of iron magne ia n w mineral like chlorite almandine-spe artite garnet or chloritoid may develop Among the garnetiferou ph lites may be mentioned the whet tone of the Ardennes Chloritoid mineral are pre ent in the ottrelite schists of the Alps Paragonite the sodium mica is commonly pre ent in phyllites

Phyllite has a wide di tribution in the cry talli e mountain ranges of the world the Highlands of Scotland mountains of Norway Harz Mountai s and mountains of Saxony the Alps, Appalachians and Great Lakes district of the United States. The schistosity of phyllites is ometimes flat b t usually is crumpled and o imperfect as to render the rock unsuitable for roofing material [T F W B]

Phyllocarida

This term has two rather different meanings in crustacean literature In the original wider ense the division Phyllocarida include both recent and fossil representatives of and is thus synonymou with the Malacostracan series Lepto traca In the narrower sen e adopted by many palaeontologi t the fossil forms are placed in the order Phyllocarida, the order Nebaliacea being re tricted to the recent ones *See* LEPTOSTRACA NEBALIACEA [I C O]

Phyllonite

A metamorphic rock—the name is a combin tion of phyllite and mylonite the phyllonites occupy a po ition between the rock type repre enting the component parts of the name There are two d tinct stages of their development In the fir t stage the original rock is granulated by extreme deformation and pulverized to a mylonite In the eco d stage but frequently overlapping the fir t stage in time new minerals recrystallize and grow (thi i called crystalloblaste i) B Sander originall introduced the name for phyllitelike rocks whi h had suffered a deformation after re ry tallizati n regardless of whether they were derived from argillites like the phyllites or from orthocataclasites *See* METAMORPHIC ROCKS MYLONITE PHYLLITE [T F W B]

Phymosomatoida

An order of Echinacea with a stirodont lantern and diademoid aml ulacral plates each interambulacral plate typically carries more than one primary tul ercle (*see* ECHINOIDEA) There are three famlie The P eudodiadematidae of the Jura i and Cretaceous had perforate crenulate tul ercles Th Phym omatidae with imperf rate renulate tubercles aro e in the Jura ic One urviving genu *Glyptocidaris* occur off Japan The Stom pneustidae with imp rf ate noncrenulate tul ercles, also range from the Jura ic and the le survi ing genu *Stomopneust s* i a comm n Indo-Pacific littoral f rm S ECHINACEA [H B F]

Physical chemistry

Phy i al chemi try lie between ph y ic and chem i try It pro ide the th retical ba i of chemi try and explain an l pre lict ph n m na in all

$$1 \text{ po e} = \frac{1 \text{ dvne sec}}{\text{cm}}$$

See DI IENSIONAL ANALY I

To fa il tate m a ur ment of ma y f tle otl er q ia t i e deri ed al i r t n tandard ha e b e e tal l h d wh l emtody r rej od t e ac urately k own or defn te al e f tl e q iantitie ch as ta da d ell f r olt ge q artz cilla to s f r f eq ency and p re liq i l f i ty

The defin g eq i t on f r the u it f me th r q i nt tie l a e nume i al ffi i nt ch $r/4$ ¼ c(= p ed of l ght) wl l refl ct g o metrical fa t r e pl y ical pr n ipl

By rb tr r ly choo ng differ nt pl y i al q is i t o wh ch t ba th n t in term of wl i h otl r q a ttt a e t l e d fi ed var tl r s tem of n t w ld be po sible II we er tl m ny d ffic lt e i m k ng experim ntal t t i e t l h h u eful ta d rd w i ld l l tll re lu d tl ere i imm d ate pr pect f inte nat al ch nge g f thes f ur qu ntit f r whi l arl trary r al l t st nd rds nd n t l been tal l d

There i h we e l kel h d that the ta dard f r th q a tt will be ha ged Sinc th fre q e cy f atomic il rati n i p rime t lly f nd t be m ch m early c t nt than i the frequ n y f the a th t t n tl t nda d f r t m m y somed y l e t ke a tran t n f e q n y f at m f partic l r t pe tli fr q e y a b dete m ed p e ely and ent e tly The t f t m tle ec nd w ll p l bly b hanged i m g itude h t w ld l e d fi ed i t rm f th atom c fr q n y S ATO IIC CLOCK

L kew th ta da d f l gth m y oon be re d fi ed by nt rn t al ag eeme t i term f the wa l ngth of a erta n p t al l n em tted by krypt n The t of le gth th m te w ld n t be h ged magnit d b t r defi d t terms f th p rt c la w el gth cho e There re two ad t g in ed fi g th ta dard f le gth in te m f wa le gth (1) the w ele gth c ll g r t d wh e eed d so th t ma y (ab l te) t d d f l gth ld be a l bl i l b t es es n h p t perm t m ac t me m nt and (2) th el e wa e l gth i p e m bly c n ta t d n ha g g wh the m t b may b s bj t t l w ha g d m s with t m and f e e s bject t d truct d m g r l S WAVE LE GTH STA RDS

Th app to be mmed t pra t c l way f lzi g ta d d f ma s f m atom p p t that w ld p mit p e n f mpa g d w be tt d w th p e e t meth d

O J ly 1 1959 by gr m t am g the n i l t d d l b t f th t u g E gl h u t ini d d d t y th l ght d ff b tw d ff e t y rd nd p nd w el mi t d by d fi g th y rd = 0 9144 m t d th p d 0 45359237 k l g m

Physical measurement

I a d e gi eer n nd n m ch of e ry day l f qu ntitat f rmati ntual f r o d ati n f cti ities d ffic ency f ommu n at T m d tan e tempe atur ol r w ght ol m d h dr d f ther phy i al q a t t e m t b d s bed i t m wh h ha th me m i g t e e yo Tl s i m de po bl by omp g the phy c l qua t ty or otl er q nt ty f t lly r l t d t t w th a c tant r p d bl qu nt ty f th am kind nd f a fi ed m g it de defined b t nd rd Th m gn t d mb d ed by th sta da d r me d r fu t n of t t ke t The e m p i th p e f m a u em nt Th g n l a f sc t fi t ty r l t to t d d f r phy l m a u m all d met l gy The m d q a t ty m y th b xp es ed by a mbe (th ma t d t o) nd the name of the t f mpl le th f 1 54 met r See U ITS SYSTE I OF

Physical standards The U S t al ta d rd f e ht nd me r ba d o r l ted t th t rm t lly a pt d t da d f r m le gth t m a d tempe at Th t d d fo l gth ba f pl t um d m k pt at the I t t I B f W ght d M a u m F e th nt f l gth th met i d fi ed a th d st b twee tw ma k th ha Th ta d d f m pl t um l d r t m t ke s th t th kil m Th t d d f r t me th y l m t f th Ea th S n tem th t f t me th nd d fi d 1/31 556 925 9747 f th t p l 1900

Th t d d f t mp t e th t mp r t r f at t t t pl p t (whe e w t r d w t po q (b m) Th n t f t m p t the d g n the Kel (th m dy m) l d fi d by t k g th t mp t f th t pl p t f w t 273 16 K w th t the b l te f t mp t (tl mo- d m all d fi d s th d t n wh h ll k et gy h b b t d f m th m l l) Th d t b e tly t t ed lth gh t b pp h d e y l ly S A OLU IIO T t L m

Th t f th phy l q tt d fined t m f th f nt by app p t d fi g q t F mpl f d fi da th p d t f ma d l t U t f l th dy the t m t g m d (g) y t m d th wt th met k l g m c d (mk) y t m d fi d by th f ll w g q t

$$1 \text{ d} = 1 \text{ gram} \times \frac{1 \text{ cm}/1}{1}$$

$$1 \text{ wt n} = 1 \text{ kg} \times \frac{1 \text{ m}/1}{1}$$

A th mpl ty th f t p t l ty g d t Th t f ty th p d fi d by the q t

what percentage yield of new products can be obtained at different temperatures and pressure The equilibrium constants are determined experimentally by measuring the concentrations of the reactants and products at equilibrium or they are calculated with the help of thermodynamics The equilibria are determined in gases or in liquid solutions

If the system contains gases alone or only one liquid solution so that only one phase is present the equilibrium is said to be homogeneous If the system contains more than one phase (gas solid or liquid) the equilibrium is said to be heterogeneous Phase diagrams describe the influence of concentration and temperature on the number of solid and liquid phases The phase rule is useful in correlating the number of phases and the number of independent variables See EQUILIBRIUM CHEMICAL

Kinetics Chemical kinetics is that branch of physical chemistry which is concerned with the prediction of reaction rates and with understanding the mechanism of chemical reactions In some reactions the rate depends directly on the concentration of the reacting material and in others on the square of the concentration Most reactions are quite complex with several different reactions going on together so that the relation between concentration and rate is difficult to determine The influence of temperature on reaction rate is important also It is large most chemical reactions at room temperature doubling in rate for each 10 C rise in temperature See KINETICS (CHEMICAL)

Electrochemistry The electrical conductance of solutions provide important information in physical chemistry Most salts and inorganic acids and bases dissociate into electrically charged ions when dissolved in water When charged electrodes are placed in such a solution the positive ions migrate to the negative electrode and the negative ions to the positive electrode The conductivity of the solution depends both on the number of ions and on their velocity When the ions reach the electrode they may undergo a chemical change to gain electrons at the cathode or to lose them at the anode There is an exact relation between the quantity of electricity and the extent of the chemical change According to Faraday s law 1 gram equivalent weight of material is electrolyzed for each 96 500 coulombs of electricity

Equilibrium relations involving ions give important information on hydrolysis solubility electrolytic dissociation and the formation of complex ions

The electromotive force or voltage of an electrochemical cell is an important quantity in physical chemistry When suitable electrodes are surrounded by oxidizing or reducing ions and arranged in pairs definite voltages are generated which can be used for calculating the free energy of the chemical reaction involved and the corresponding equilibrium constant The potential between a single electrode and its surrounding ions depends on the chemical nature of the ions and on the concentration Hydrogen electrodes are widely used for determining the effective concentration of hydrogen ion See ELECTROCHEMISTRY

Colloids Colloids are very small particles which possess very large surface areas for a given weight. They adsorb ions take on electrical charges, and acquire special properties which differ from those of true solutions and from systems which contain large particles The study of colloid is a branch of physical chemistry which finds many applications in biology and in industry See COLLOID

Molecular structure Much valuable information concerning the chemical and physical properties of chemical compounds can be obtained from a knowledge of the molecular structure The arrangement of atoms and electrons within the molecule and the attractive forces which hold them together can be determined from physical measurement of refractive index rotation of polarized light, absorption of light of different wavelengths diffraction of electron beam and dielectric constant Predictions of chemical behavior are made on the basis of the type of bonding The electron pair which holds atoms together is particularly important in organic chemistry and the electrostatic binding is particularly important in inorganic chemistry Quantitative calculations are made on the basis of quantum mechanic

Ordinary thermal chemical reactions are brought about by activating collisions between rapidly moving molecules They can be brought about also by the absorption of light The branch of physical chemistry which studies the relation between activation by light and chemical reaction is known as photochemistry Chemical activation produced by very high energy radiation such as x rays or by radioactivity is studied in a branch of physical chemistry known as radiation chemistry See CHEMISTRY MOLECULAR STRUCTURE AND SPECTRA PHOTOCHEMISTRY [F D]

Bibliography F Daniels and R A Alberty *Physical Chemistry* 1955 S Glasstone *Textbook of Physical Chemistry* 2d ed 1946 C F Prutton and S Maron *Fundamental Principles of Physical Chemistry* 1951

Physical law

A physical phenomenon is said to be controlled or governed by a physical law when the phenomenon is one of a broad class of phenomena such that it is possible to formulate some regularity which applies to all members of the class If the phenomenon on which can be described in terms of numeric measurement the law is often formulated in terms of mathematical relations between the numbers obtained by measurement as in the inverse square law of universal gravitation However a mathematical formulation of a natural law is by no means necessary

It is implicit in the notion of physical law that there are no exceptions and unlike man made law it may not be violated

to d t o with c ntrolled variat on in the factors c nsid r d s pos ble ou ce of rr r perm tt g stat stic l t mat o of the mag itude of the ari s ror a d app op iate cor e t n for them [W A W]

Bibl og aphy Se INSTRUMENTATION

Physical science

The fields f inquiry to wh ch the g neral des gna tion c en e m y b appr pr ately appl ed are broadly d ided into ocial sc ence and natural c n The latter is furthe ubd vid d i to b ol gy and phy i al c e ce Phy i al c ence i gen lly c n idered to include a t omy chemistry geology min ralogy m teor logy nd physic These o e lap more or le as ll t ated by a t o phy c hem al phy es phy cal chem i try and *geophys cs Th e is rlap* f kewi e between th *phy al a d b log al sc enc s a seen in b o ch m try b oph y c* n l gy a d the el se r la t on b twe n geol gy a d p leontology The b unda impl ed n all u h cla ifications are arti fi l nd n t of r g s whe one fi ld l d to a th r

Ch m t y a d phys c d ffer fr m a tro omy m t o l a d g l m th t il are c n e ed w th th p p tes f matter and energy u te ed at k upon and withi the arth the pl n t d t s F th e on h mi try a d phys c a ot t apart f m b t athe p ade th oth n

T eg rd the ev al a e f c ent fi nqu ry a pa t d by ha p defi abl bo nda ie s r l ti C f rtil zat o h s produced ome of th m t n tabl d an e in en e d a a t fi al b t e d antagen ly be a pted a a ll nge by sc t t w th n d tur m d S SCIENCE [J H R]

Physics

Th g al t, f phys c fo me ly lled at ral ph l phy w t u de ta d th st uctur f the at al w ld d xpl n atu al phen m l t m p l d a e b ok w y f m phy t f m t om field f t g t In th p o phy c r t ed t g n f m of g t lf w th th sp t f n tu wh ch ld be nd r tood f nd m nt l w y t rm f l me tary pt spl a d l w

Basic parts The m t b p t f ph i m ha t a d fi ld theo y M h ni n d w th th m t f p rti l r b d e d th f g f Th phy of fi ll i d w th th g t e a d p opert s of gr t t al el t m gn t c, n l d oth r f fi ld T k t gethe m h d fi ld theo y c t t t th m t f lam t l ppr ch t d t d g f t l ph m wh h n ff Th h m t a m t de t nd all t al ph n m n th t rm S FIELD T O Y PL MECHANICS QUANTU FIELD TH Y

The lder or cla ical di i ions f phy ic w re ba ed on certain general clas es of natural phenomena to which the methods of physics had been found pa t cularly appl cable The e c n i ted of classi al mechanics with branches in celestial mechan cs hydrodynamics and balli tics heat and thermodynamics k netic theory of gases and statistical mechanics optics acoustics and elec tr city and electr magnetism These divisions are all still current but in pre ent usage many f them tend m re and more to de ignate branche of applied physics or technology and le s and les in he ent divi ions in physics it elf

Branches of modern physics The divi ions or branche of mod rn physic are made in accordance w th part cular types of st ucture in nature with which each branch is concerned Thus elementary particle or ultra high e ergy physics is the mo t recent branch and i concerned with un de t ndi g the p opertie and beha ior of elementary particle as such and more particularly of the h vy u t ble p rt cles—m son hyperon and nt pa ticle —which are produced in collisi ns in ol ing en rgies bo e abo it 150 000 000 lectron olts The ne t b anch in this cla ificati n is nu cle r phy s whi h i concern d with a ocia ti n of neutrons nd prot n f rm ng the nu le of at m the r t uctu e p pert and e rgy t tes react ns betw en nuclei i cl d ng cat t ring pr ces es nd rad oact v ty a d r lated ph omena u h as th interaction f h gh peed n lear part cles w th matter Atomi phy cs i c n erned with the truct e a d p p rt es of at ms d term ned by the electr s ut ide the nu l us th tate of m ti n f the electr s in cl di g a ch t pic a e gy le el ng l mom nt m pr pertie nd magn ti m me t and the ab pt n nd emi s on f rad ti by at ms

Co t uing w th th la fic ti i a c nd ng ompl x ty th re m lecul r phy c wh h i ncern d with sy t m of at m fo med i to m le cul s th st e f te mol ul r f s chemi al t nd ng v brati and t t on pect a f mole c l and th l ke Next in o d are olid tate phy c phy f liq id phy c of ga es nd more rec ntly pla m phy c whi h deals w th propert f h ghly ni d toms f rm g a mix tur of b n lei a d el ctr n called an i n pla ma

I th s am la ificat n co ld also be i clud d b ophy wh h d al with the appl atio of phys l m th d nd typ of e pl tion to b o l g al sy t m nd st u tu es

Oth m re spec h d la fications may be m d n cc rd nce w th p i cular in tr ment r t hn qu ch as x ay d ffract n ne tr n d ff t ma p i metry inf a ed sp ct py and e m l y The p i l field f l w temperature phy c hara te ed n t ly l y sp c al n t u m nt ol d i th p od ct o a d m su m t f l w t mpe t th range of l qu d helium b t lso by the ph men f t per n du ti ty and pe flu d ty wh ch cc o ly n thi tempe atu

The corresponding value of the inch is now 2 54 centimeter exactly The old United States yard and inch had been about two parts per million larger than the new yard and inch

Accuracy of measurements In general any measurement has less than perfect accuracy there is some error or uncertainty as to the true or exact numerical ratio between the measured quantity and the unit These errors are either observation or calibration errors Observation errors are errors or uncertainties in reading scales and interpolating between scale divisions or in synchronizing the readings with the events Calibrational errors are errors or uncertainties in the conversion factors relating the primary measured quantity and its representative quantity (such as when acceleration is measured in terms of the voltage generated in a piezoelectric material) or in the relation between the indicated readings and the units of the final measured quantity

There are practical limits to the statistical exactness of comparison even with repeated measurement Furthermore there are other sources of error due to inherent imperfections of materials and structures which cause the phenomena of drift lag hysteresis damping and re onance

Drift is the gradual change of instrument reading after a change to a different but constant value of the measured quantity

Lag is failure of the instrument reading to follow changes in the measured quantity instantly or exactly The time constant of an instrument is the time required for the indication to change by $1/e$ of a sudden change in the measured quantity in response to this change *See* TIME CONSTANT

Hysteresis which results from lag or drift i the difference between readings of the measured quantity for corresponding actual magnitudes of that quantity when the quantity is increasing and when it is decreasing

Damping is the result of frictional forces (either viscous or coulomb) which cause greater lag than that due to inertial effects alone *See* DAMPING

Resonance is the condition of oscillation which results when the rapidity of change of measured quantity is close to the natural rapidity of response of the instrument *See* RESONANCE (ACOUSTICS AND MECHANICS)

The change of properties of materials or structures with temperature pressure humidity radiation vibration or other environmental conditions may also cau e errors Thus the analysis of experiments to detect all possible sou ces of error the design of experimental procedures to minimize them and the development of mathematical techniques for estimating their probable magnitudes constitute an important part of any measurement in which precision is important

Measurement techniques The comparison of quantities as to equality the counting of un ts and the determination of the coincidence of e e its—all involved in physical m asurement—may be done by an observer (usually using his isual aural or tactile faculties) or by instruments which di play or record the results or apply them to automatic computation or control *See* INSTRUMENTATION

Direct measurement involves comparison with a standard (such as a meter bar) or measurement by a calibrated instrument (such as a voltmeter) Indirect measurements are those derived from mea urements of related quantities for example the mass of the electron can be derived from mea urements on the bending of the electron path in a magnetic field and separate mea urements of its charge Ab olute measurements are tho e derived from measurements of the primary quantities involved as in determination of acceleration from length and time intervals rather than from reaction force

Once a standard of any physical quantity is established (by definition or absolute mea urement) any instrument of known stability calibrated by measuring the standard or multiples or di i ion thereof may be u ed as a standard in trument to calibrate other instruments by compari on of readings when measuring constant or repeatable values of the quantity

Space permits mention of only a few special techniques devised to reduce uncertainties and errors in measurement

1 In weighing on a balance known weights are substituted for unknown weights previou ly balanced by counterweights so that such uncertainties as knife edge placement and beam lengths do not affect the comparison

2 The effect of a quantity to be measured may be nearly off et by a imilar known and fixed quantity and the difference measured by an instrument of lesser range and of correspondingly higher precision

3 If the standard offsetting quantity can be divided into sufficiently small or continuou ly variable fractions it can be adjusted for equality to within the smalle t limits detectable This is the so-called null or balancing method of measurement.

4 A number of small quantities of the ame kind may be combined so that the cumulative magnitude is appropriate for measurement with a ailable methods

5 The measurand may be time modulated to permit better di crimination between the mea urand and extraneous effects on the measuring in st ument

6 The undesired effects of en ironmental factors such s temperature and external magnetic fields may be compensated for in the instrument system by elements whi h are respons e to the disturbing facto and interact with the measuring or ind cating means to ffset such effect

7 A series of observat ons of a part cular measurand perm ts statistical determinat on of an a erage and lead to increa ed preci ion also an estimate of the probable erro of observation (not includi g systematic er r) can be obtained

8 Based on caref l de gn of experiments observations may be made a wide ar

d t ns w th at lled e r t on the factor on d r d as p s ble so r es of erro perm tt g tat st c l e t m t on of the magn tud of the ar s rro s a d approp te c r e t on for them [W A W]

Bibliogr phy Se INSTRUMENTATION

Physical science

Th fi lds of inqu ry to wh ch the gener l d s gna ti n sc may be pp opr ately appl ed are broadly d v ded nto c al science and n tural c nce Th latte s furthe subd vided into b ol ogy d physic l s enc Phy ical scie ce i gen e ally o dered to include a tr nomy chemistry geology m e al gy meteor logy a d phys cs Th e o e l p m e or le s ll trat d b a t o phy c chem al phy i phy ical chemi try and g phys cs Th e lap likew se between the phy ic l and bi logi al s ences a een n b o-ch m t y biophy cs v r logy d th clo e rela t n b tw en ge logy a d pale nt l gy The bo da ies impl ed i ll u b cl s fi at on re art fic l a d n t of eg n whe e o e field h des nto an the

Chem try and phys cs d ffe f m st m meteo ol gy a d geol gy i that they e con ned w th th pr pe t e of matt r nd energy u te ed l k upo a d w th n the rth, the pl t d t F r th a h m try a d phy i e n t t part f m h t ath y rv d th the nc

T reg rd th e er l e s f nt fi q ry p rated by h p d fi bl bou d ries u al t C ferti l zat on h p od ed som f th m t n t ble ad e t sc n a d a rt f l ba e a d a tage u l l ccepted as a h ll ge by e t t with d atur u m nd SCIENCE [J H H]

Physics

Th g al bje t e f phy i f rme ly c lled at l ph l phy w t und t nd th t u t e f the t l wo ld and epla at ral phe om l t m a p l d ces br ke w y fr m phy t f m t om s field f n t g t l th p oce phy e t ed t r g al m i r g t elf w th tho e spect f tu wh h ld b d tood n a fu da me t l way i term f l m nt ry p n ple nd l w

Basic parts Th m t b y t of phy c a h n and fi ld thec ry Mech n rned w th tl m t n l part les bod es nde th e f g f ces Th ph i of field n ed w th th g n n t d p p rt e of g a t t al l t m gn t n l d ther f field T k t g ther m ha e d f ld theo y t t t the m t f ndam t l pp h t nd t nd g f n t al ph m wh ch sc ff Th ult m t a m t nde t nd all at l ph n m n in the terms S FIELD THEORY CLAS C L M CH IC Q ANTUM FIELD t RY

The older r clas ical di i ions of phys cs were ba ed o certain g neral cla es of natural phe omena to wh ch the methods of phy i s had l en found particularly appl ble The e con i ted of cla cal mechan cs w th branches in celestial mechan cs hydrodynam cs and balli tics heat and thermodynamics kinetic theory of ga es and statistical mechan cs optics acoustics a d elec tricity and electromagn ti m The e d isions are all still current but in pre ent u age many of them tend more and more to designate branches of applied physic or technol gy and less and less in herent d visions in physics it elf

Branches of modern physics The d vi ions or bra ches of modern phy cs are made in acc rd ance w th partic l r types of struct res in nature with wh ch each branch is o rned Thu ele me tary part le ultra high energy physics th most re e t branch and i concerned w th un derst nd ng the prop ties and b h r of elemen tary part cles s h and more parti ularly f the hea y n table part cl —me hype and antipart cles—which re p oduc d in ll s on in ol i g energ es bo e about 150 000 000 electr n olt Th ne t b an h in th cla if at on is nu lear phys c wh h is ncerned with a oc tion of n ut ons and pr t n f rmi g the nu lei of atoms thei st tu pr pe t e a d ergy tates re t s betwe nu lei including cat t i g p o e es and rad acti ty and lat d phe ome a su h as the intera ti n of high peed nu lea particl s with matt r Atomic phy ic is n e ed w th th tr ctu and p opert es of atoms a determ ned by the lectr n outside the nucl the tates of m t n f th elect ns in l ding h topics a ne gy level a g il mo m ntum prop rt and magn tic mome t and the ab pti n and emi io f adi t on by at ms

Conti i ng with thi cla ifcat n i nd ng c mplex ty there is m l cular phys wh h is co e ned w th sy t m f at m f rm d to m le ul s the at e f int rm l ula f rces chemic l b di g b atı a d rotat on p ctra f mole l nd th l ke Next i o d r a olid tate phy ics physı l qu d phys c of ga e a d m e ently p la ma phys c wh h d al with prop t es f h ghly ion d at ms fo m ng a m tu f ba e nu lei and le trons c ll d n ion pl m

I th m l s fi at o c uld also be cluded phy whi h deals with th appl c tion f phy c l m thods a d typ f pla at on to b o-log l yst m d tructu es

Oth m re pecial z d cla s fi at on m y be m d ac d ce w th part cul r i st um nts or te hn q h s y d ff ct on neut on diffrac ti ma s pe t m try nfr ed p tr py nd m logy The p cial field of low t mp rat phy har t d n t ally by p ci l n tr m i v l d n tle p d t n a d m a u ement of l w t mp tu n th r g f liqu d h l um b t al by the ph n m na of s p rc d ct ty a d pe fl id ty whi h occ ly n thi t mp tu e

range Other fields such as astrophysics and geophysics are concerned with aspects of other sciences to which physics is applicable

Mathematical physics is the study of physical phenomena by means of mathematics and includes the more mathematical parts of all branches of physics as well as most of the content of statistical mechanics quantum mechanics relativity and field theory A distinction is often made between mathematical physics and theoretical physics in which the latter although still entirely mathematical in form is thought of as being more closely related to experimental physics Neither mathematical nor theoretical physics can really be separated from experimental physics since a complete understanding of nature can only be obtained by the application of both theory and experiment

Aim of physics In every area physics is characterized not so much by its subject matter content as by the precision and depth of understanding which it seeks The aim of physics is the construction of a unified theoretical scheme in mathematical terms whose structure and behavior duplicates that of the whole natural world in the most comprehensive manner possible Where other sciences are content to describe and relate phenomena in terms of restricted concepts peculiar to their own discipline physics always seeks to understand the same phenomena as a special manifestation of the underlying uniform structure of nature as a whole In line with this objective physics is characterized by accurate instrumentation precision of measurement and the expression of its results in mathematical terms

For the major areas of physics and for additional listings of articles in physics see ACOUSTICS ASTROPHYSICS ATOMIC PHYSICS BIOPHYSICS ELECTRICITY ELECTROMAGNETISM HEAT LOW TEMPERATURE PHYSICS MECHANICS CLASSICAL MOLECULAR PHYSICS NUCLEAR PHYSICS OPTICS SOLID-STATE PHYSICS THEORETICAL PHYSICS

[W C P]

Physiological acoustics

A term used to refer to the physiology involved in the process of speaking and hearing Physiological acoustics includes the action of the larynx glottis throat mouth tongue and teeth in the process of speaking It includes the action of the eardrum the small bones of the middle ear the inner ear consisting of the oval window cochlea basilar membrane and round window and also the action of the nerves carrying the acoustic stimulation to the brain in the process of hearing A study of the effect of various kinds of sounds upon all the physiological processes in the body is also included in this field The term physiological acoustics and psychoacoustics are sometimes used interchangeably Technically however only the topics mentioned here fall under the domain of physiological acoustics See HEARING SPEECH see also PSYCHOACOUSTICS

[H F L]

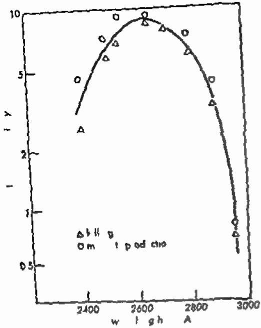
Physiological action spectra

An action spectrum is a representation of the comparative effects of different wavelengths of light on living systems or on the components of living systems A knowledge of the effects of different wavelengths on living systems helps lead to an understanding of the detailed mechanisms of energy transfer and utilization and to a determination of the essential compounds involved in light action of living systems The work of action spectroscopy is founded on the firm bases that energy must be absorbed before it is utilized and that each chemical compound has a characteristic absorption spectrum Therefore the shape of the action spectrum may lead to the identification of the absorbing molecule Action spectroscopy has been used extensively to study three classes of compounds porphyrin containing proteins nucleic acid polymers and plant pigments See ABSORPTION (ELECTROMAGNETIC RADIATION)

Beneficial effects of light Proteins which contain porphyrin prosthetic groups such as hemoglobin and cytochrome play an important part in the transport of oxygen and in the oxidation reduction systems of cells Such prosthetic groups have a high affinity for carbon monoxide (CO) and therefore the respiration of living systems is inhibited by carbon monoxide Light can remove this carbon monoxide inhibition by causing the dissociation of the porphyrin CO complex The extensive studies of O H Warburg and his collaborators on the action spectra for the removal of the carbon monoxide inhibition respiration led to the identification of the respiratory enzyme as a porphyrin containing protein The fact that light absorbed not only in the porphyrin ring but also in the protein can cause the dissociation of CO indicates that energy may be transferred over distances of about 30 angstrom units (A) See CYTOCHROME HEMOGLOBIN PORPHYRIN

Destructive effects of light The beneficial effect of light mentioned above is to be contrasted with the destructive effect of light in the ultraviolet spectral region This light can destroy the enzymatic activity of proteins and can kill bacteria and viruses Action spectra for the killing and the production of mutants in yeast shown in the accompanying figure indicate that the most sensitive wavelengths are in the neighborhood of 650 A The shape of the action spectrum is very similar to the absorption spectrum of nucleic acid and indicates that nucleic acid polymers are essential components in the duplication of living systems Some of the effects of ultraviolet light on deoxyribonucleic acid (DNA) are reversed when the system is illuminated by intense visible light Such reversibility is known as photoreversal or photoreactivation See BACTERIA NUCLEIC ACID PROTEIN ULTRAVIOLET RADIATION (BIOLOGY)

Photosynthesis Because the sun is the most important source of energy it is not surprising that



Th ct p t f th k ll g f y o t d th p o- d t f m t t y t by lt ol t ight (All d I C R t d W L Smp A h B h m B phy 57(1) 18–228 1955)

ph t ynth s e f th m t tho o gl ly tud d f th fi ld wh h e n e n th rgy ex ha g b t l ght nd l g syst m The ide t f ts f hl ophyll a t } mpo t of ph to- the t mad by mpa t g tl a tn n p t m f r ph t s the w th th ab pt on p tr m f hl oph ll Th m l ty b tween th tw d c t th le tk t hlo ophyll pl a a ph t y th O the th h d the ctt n spectra f ph tosynth t n some lg a d not mble th b pt n p tr m f hl gh ll l th c l ht b bed the p gm nt m l l d th t n fe d t hl to- phyll t be ed f ph t nth A t p tr h h n th e t ten e f w l ngth dep nd t ff t n ch d ph t p d p opert es f l t g th ng s the ge m n t of l the fl we g f pl t i th h g n olo ati n f mals w th the s n All th e ff cts rmed by l bor te t pl y b twe n ed nd fa d l ght

Mechanism Th f am ry p n l ght a t o th b pt f l ght q a t m by m l l Th m l l thu r ed to m c t d t t Th x t t gy m y b pa d n t th r m l } nd t l z d f r hem l r ct n n ph t ynth th xt ergy m y b d t b k b d nd alt hem l t t th n ct t f ba t r a by ult I t l ght o tf x itat n e gy may b r mitted fl t l ght ult m t ly d g d d a h at I th l tt r th m y be ffe t f th bso b d dat n at ll A p rti la ly t e t ng f tu e

of ex ited tates t the al lity of energy t l e tr ferred over appreciable l tance fr m one molec l t anoth er by a pr kn w a energy tran fe S t h pr ce perm t energy al sorl ed n ne mole l t app ar in a d ff rent typ f molec l Th x te n f e n n en rgy tran fe may l e inferred fr m c mpari n of th act n abso pti n and the flu re t spe tra of the r adiated mat r al S CHLOROPHYLL PHOTO- PERIODI M I PLANTS PHOTOSYNTHESIS VISION [R B S]

B bl og aphy A H lla nd r (l) *Rad ati B ol gy* ol 2 1955 ol 3 1956 C Re d *Exc it d Stat s in Chemistry a d Biology* 1957

Physiology general

A d i f phy i l g al sc en e in which the ba ic a t it e f l ng rgani ms that oc ur in m t ll and ti ues are t id ed by phy ic l and ch m al meth od It l ving materi l rang fr m th imple t unicell l r form to m n him lf Th x d t n and redu tion whi h re f uns r al cur en i l th pla t and animal ar ampl es f uch l a ic ct t es Many cell a c t m late ertai t n w th n th ir ytopla m wh le te d ng t xcl de thers l n grad e t re th re- fo typ lly pres nt ac o ft ing meml nes as- oc ated with the development f electr m ti forces (BIOELECTRIC TOOTL) Num r us ch mical a t o cc rring with n ll a speeded by or gan tal) t k own a zymes wh se m d f a t o s m lar thr gh it the li i g w rld Th expe im nt l tudy f h l a phe me a con t tut th fi ld f g ral phy i l gy

I m thod a d ubject matter gen ral phy i l gy d ffe s o d rai ly f om mammalian physi l gy The latter de i n f the sci nce de l par t ula ly w th the f nct nal act v t of th m t h ghl dev loped a imal It ft be m s ad p n of m d al p a t w th littl c n ide t n of b c p c pl lt te ds t l rg phy ol h h a l an Pa l rema ked ha l e gr its t dy fr m the m d t f hl the beg nn ng th ba f l fe s th ell C n l phy iol gy mu t l o b d t ng hed fr m c mp t ve physi- log n wh ch empha i s placed as m h upon th diffe n c b tw o g m a up n their m l t H w e no h rp d t ction ca b mad betwee th thr e bd v s o f the bj t The w ll t ed by l g t d aw h s mat ls f m ll

Development Long befo e gen l phy iol gy me ged a s pa ate d cipl b ry t ons w e m l t ng wh h p p ly bel g t it Thu th g t n fel t ty by li ing ga m t tute a impo t t ch pt n al phy l g al th ht Tw p of l t al f h w e kn t th n i nt C e ks and E yp- t a The R m n phy ns u ed th h ck g n e t d by T p d ist at a o h m di e th s n ug r t ng l t h ck th apy f t t n the ea n l w s a pot nt fa t the d l p-

range Other fields uch as trophysics and geo physics are concerned with aspect of other ciences to which physic is applicable

Mathematical physics is the study of phy ical phenomena by means of mathematics and includes the more mathematical part of all branches of phy ics as well as most of the content of tatistical mechanics quantum mechanics relativity and field theory A distinction is often made between mathe matical physics and theoretical physic in which the latter although till entirely mathematical in form is thought of as being more clo ely related to experimental physics Neither mathematical nor theoretical physics can really be eparated from experimental phy ics since a complete under tand ing of nature can only be obtained by the applica tion of both theory and experiment

Aim of physics In every area phy ics is charac terized not so much by its ubject matter content as by the precision and depth of understanding which it ek The aim of phy ics is the construction of a unified theoretical cheme in mathematical terms who tructure and behavior duplicates that of the whole natural world in the most comprehensi e manner po sible Where other ciences are content to de cribe and relat phenomena in terms of re stricted concepts peculiar to their own di cipline physics always eeks to understand the ame phe nomena as a special manife tation of the underly ing uniform structure of nature as a whole In line with this objecti e physics is characterized by ac curate instrumentation preci ion of measurement and the expression of its results in mathematical terms

For the major areas of physics and for additional li tings of articles in phy ics see ACOUSTICS AS TROPHYSICS ATOMIC PHYSICS BIOPHYSICS ELEC TRICITY ELECTROMAGNETISM HEAT LOW TEM PERATURE PHYSICS MECHANICS CLASSICAL MOLEC ULAR PHYSICS NUCLEAR PHYSICS OPTICS SOLID STATE PHYSICS THEORETICAL PHYSICS

[W G P]

Physiological acoustics

A term used to refer to the phy iology invol ed in the process of speaking and hearing Physiolog cal acoustic includes the action of the larynx glottis throat mouth tongue and teeth n the process of speaking It include the action of the eardrum the mall bones of the middle ear the nner ea consisting of the oval window cochlea ba la membrane and round window and al o the acti n of the nerves carryi g the acou tic st nulation to the brain in the proces of hearing A tudy of the effect of various kinds of s unds upon all the phy siological pr cesses in the b dy is al o include l in th s field The terms phy iol ic l acou t cs d psychoacou tics are ometime u ed inte change ably Te hnically however only the top cs men tioned here fall u der the domain of ph siologi al acou tics *See* HEARING SPEECH *see lso* PSYCHO ACOU TICS

[H FL]

Physiological action spectra

An action pectrum is a representation of the com parative effects of different wavelengths of li ht on living systems or on the components of li ing s tems A knowledge of the effects of different a e lengths on living systems help lead to an under standing of the detailed mechani ms of ene gy tran fer and utilization and to a determinati n i the es ential compounds involved in light action of living ystem The work of a tion pectro copy is founded on the firm ba es that energy mu t be ab orbed before it is utilized and that each chemical compound has a characteri tic ab orption pect um Therefore the hape of the action pectrum ma lead to the id ntification of the ab rbin m le cules Action spectroscopy has been u ed exten si ely to study three clas es of compound por phyrin containing protein nucleic acid polymers and plant pigments *See* AB ORPTION (ELECTRO MAGNETIC RADIATION)

Beneficial effects of light Proteins h ch con tain porphyrin pro thetic group uch as hemo globin and cytochrome play an important part in the tran port of oxygen and in the oxidation red tion system of cell Such pro thetic group ha e a high affinity for carbon monoxide (CO) and there fore the re piration of li in y tems i inh b ed by carbon monoxide Light can remo e th ca bon monoxide inhibition by causing the di ociat on of the porphyrin CO complex The exten i e tud e of O H Warburg and hi ollaborators on the action spectra for the remo al of the carbon mon ox de inhibition respiration led to the identificat on of the re p rator enzyme a a porphyrin conta ing prote n The fact that li ht ab orbed not onl in the porphyrin ring but al in the protein can cau e the di sociati of CO indicate that energy may be transfe red o er di tance of about 30 angstrom nit (A) *See* CYTOCHROME HEMO GLOBIN PORPHYRIN

Destructive effects of light The beneficial ef fect of light mentioned above is to be contra ted w th the de tructi e eff t of light in the ultra iolet spe t al e ion Thi light can de troy the enzy matic activity of p ote ns and an kill bacteria and u es Act on spectr for the k ll n and the pr ucti n of mutants in yea t ho vn in the ac m panyi g figure indi te that the mo t en it w elengths ar in th neighborhood f 2650 A The sh pe f th ction spe trum is ery imilar to the abso ptio pe trum of nucleic acid and in d cat s that nucle c acid p lymers are e ential compo ents in the dupli tion of li ing y tem Some of the eff cts of ult i olet l ght on deoxyri bonu l ic cid (DNA) are re er ed hen the s tem is ill m ated by inten i ible li ht Such re er ibility is kn wn a phot e e al or photore ct ation *Se* BACTERIA NUCLEIC ACID PROTEIN ULTRAVIOLET RADIATION (BIOLOGY)

Photosynthesis Il ca e th e un i th e mo t im portant ce f en gy it i not su p ing that

alk d g e It hydr g n on e trat n i p t c lly n ari ble be ng m i t i ed largely by buffe system of bica b nat and ca l me a id It ha furn hed ther f re a ptum l n nment for th appe f l n g n m

The c nt i t s f Rud lf H b r l g the le d n G rman holar th field nd Will am Madd k Bayl b t kn wn Engl h w iter may me t oned Follow g in the Be n rd trad tion b in 1915 d l r d th t it not o ly p le b t of imp rta e t anchor phy l gy n e pe n ph al l emi try than wa done p evi u ly A mil r emphas e u m st of the ther p bli l d w in wh h may be found d f d ffu o mo nd o m t pre ure llo d l state w te a d lectr lytes hyd g n c nt t n x dat o and ed ti n enzym t n a d the effe ts of t mpe atu e n add t o o t tment of the at re of p topl m the p r n ab l ty f memb n t t n e r ti n d g tio sp ati n and metab l m e it tio t l h b t muscul r tra t on and n rve nd ct I d d the e segm t f phy l g c l t dy wh ch may t be c der d the b d p rt of gen al phy l gy Th e n is a m tl od of app oa h a d an attit d of mi d athe th n treatm nt f a y p rt ula topi y sp l field S O HOREGULATORY MECHANISMS

Areas of general physiology Altho gh g ne al phy ol gy i fa m tl n c ll phy i l gy and ch t h h t level nl n t t gr ti thi k ng cern ng th wh l ga i m l ge seg m t f t l t tu e h b n d ted t tud e of c ll perm b lity p rt c l l f th t pla ma m mb n Fam li m t ial f s ch t de a e l pla t ell the egg ll f in teb ate nd rteb at d bl d rpu le By a v r t f m th d the p n t t on f many ub t e h b n st d ed N fa t r can nt f th l rv d pe t t M l ul f m ub t c f i sta c w t xyg a bon d de a d u e an t a d l a th cell the a m ll d a d ly make th t w y th gh mall p re the membr I m y c th ab i ty f n n l tr lyt to p n t at t l a t p rtly l t d t th l p d olubil ty f th m t l E O t n t ed i 1899 I th a e l le tr l t th el t i al h rg on the wall f th m mb a po es eems to det m th p Wh n the m mb n harg s l tr g t s t lly the a e p t ely h ged ti n pe tr r m h m r ead ly th n d n g t ly h g d n o Whe th m mb a ha g l ct p t e s th rt b te red blood rp l o t t m st re d ly n f ne tgn a p fe e t ally l d d l t lyt p s g l t ly d ffi ult a d th lect l t n of l g memb la t l h gh In th ual the l rger rg m lec les h s f t o p oten n t nte l ng ll u h lth ugh th r e nt t t buld g t the l tty e d d am n d ble t d H we r ti in p al t

ati n as in the cell of the liver there is e idence th t molecule of the pla ma pr teins can enter and lea with rel tive ea e See CELL (BIOLOGI CAL)

Models At an earlier tim wh n mu h les wa known ab t ell stru ture and f net n ther wa a tt ng t nd ncy among general ph y i l gi t t eek a d in tl e r th nking by tl e c n tru ti n of models I o g n c o n nli ing ganic s tem m y b built t imitate me vital acti ity althou gh they a e n r l le t reprod c all f its a p t The r o tructi n mpl as z the desi e of in e ti gato s i thi field to deal with uni er al phen m ena A s mmary desc ipt n of many f the mod el was g ven by T C B rne in 1937 Tl ey in lude I Traul e model of th cell c n eived in 1867 wh ch wa f rmed l y letting dr p of gelatin fall nt 5% tan ic ac d whi h c the f rm ti n f a p cipitati n memi rane ar nd tl e gel t The e artificial ell m ml ranes are s ff ently d n t p e t the perme ti n f gluc If glu c e is added t the g latin l ef re the c ll are f rmed it later ca e th m t well l a of s mot mo ement f water i t them N Harvey i 1912 f rmed artif ial cell l y adding egg whit t water then sh king w th chl f rm nt l p o te co ted hlorof rm droplet appea ed If lecı th n is added to the hl r f rm a d the chlo of rm dr plet are all wed t e apo te i water pr tein c ered lec th n ell remai whi h re mbl a u him ggs i m ny p ope t es

Traub t l o po l le f r the introdu tion of a mod l of the c ll m mb ne which has been w dely mpl yed i phy cochemical tud es Wh n a olut n of pot um f rr yanide comes int c t ct with o e of pp r ulf t a m mbrane of ppe f rro yanide is formed wh h may be sup ported a p r s p rcel cup It perm t the pa s g of water and a few th mall m le ule but e clude s ga and la g r m le le This membrane cl ly appr xim t the ide l emiper meabl membr ne h ch i pe meable to wate b t to no s bstance dissol ed n th water Living ell m mbra a e ften call d m permeable but it mo e n arly c t t peak f them as l ti ely p meable

S ch model exp m t ha e a rta n pedagog i al alue and m y ev n d in the pl nni g of ph ologi al xp r m nts But t s the v t l acti ty wh h ugge ts the model a d t the eve e The in e t gat sh ld fo u h att nt n upon th l ng c ll o g n m t wh h hi phys cal and hem cal exp rim t l m th ds h uld be d e tly applied

Us f th l t mic p In th la t dec d a g e t expa s of b ol gi al knowledg has r ed th ugh th w de p ead u e of the el t m e c pe wh h pr v de a ealth of new l m t n o erning tl e ultr tr cture f cell a d t s Th fin r an t my of llular n l o u h the m t chondr a a d th G lg ap pa at s b g rev led A syst m of flu d filled t be k ow a the e d plasm c r t c l m h s

ment of electrical science in the eighteenth century Alessandro Volta called his voltaic pile an artificial *Torpedo* See ELECTRIC ORGAN (BIOLOGY)

Physiological observations on living cells have led to other important advances in physical science In 1827 Robert Brown reported on the general existence of active molecules in organic and inorganic bodies In examining the ovules and pollen grains of various plants under his microscope he observed small particles within them to be in rapid oscillatory motion A systematic search revealed the same phenomenon in the most diverse materials In his honor it came to be known as Brownian movement It was later recognized as due to the thermal agitation of molecules and ions in the cytoplasm and in other fluids Their own movement is invisible but their continual bombardment of particles suspended in them causes the visible oscillations This thermal activity is basically responsible for the diffusion of material along their concentration gradient in solid liquid and gases

There are several further examples of physiological experiments leading to physical discoveries In 1748 J Nollet discovered osmosis by observing that a pig s bladder filled with alcohol and dipped into water increases in volume as water moves into it The experiments of H De Vries beginning in 1884 showed that if a sugar solution of a certain molar concentration just produces plasmolysis of plant cells the same effect can be produced by a lower concentration of sodium chloride or of other salts J Van t Hoff and S Arrhenius shortly used this data to support their theory of electrolytic dissociation arguing that each salt molecule upon solution splits into ions both of which contribute to the osmotic pressure whereas the sugar molecules remain undissociated

Thus general physiology is more than a study of the functional activities of plants and animals Broadly conceived it is a search for phenomena which are universal occurring in both the living and the nonliving worlds to the end that a more fundamental understanding of vital activities can be attained *See* ELECTROPHYSIOLOCY (HEART)

Development of general physiology General physiology was first established as a distinct discipline by the devoted labors of the great French physiologist Claude Bernard (1813–1878) who introduced the term In a series of brilliant investigations he added greatly to the subject matter of the science His experimental studies included the mechanism of glandular secretion (particularly in the pancreas) animal glycogenesis vasodilator and vasoconstrictor nerves animal heat anesthesia poisons (especially curare and carbon monoxide) and a wide array of other subjects

In 1865 Bernard wrote that general physiology is the basic biological science toward which all others converge Its problem is to determine the elementary condition of vital phenomena Thinking more specifically about methodology he argued that the properties of living matter can be learned only through their relation to the properties of inorganic matter it follows that the biological sciences must have as their necessary foundation the physico-chemical sciences from which they borrow their means of analysis and their method of investigation

Bernard s final review and summary was published in 1878 In it he developed his conception of an internal environment in the higher organisms whose composition and physical state are so regulated particularly by central nervous reflex action that their cells live in a nearly constant fluid medium distributed through their blood lymph and intercellular fluids His famous dictum *La fixite du milieu interieur est la condition de la vie libre independante* is usually translated the constancy of the internal environment is the condition of the free life" but this rendering loses certain of the original force by omitting independent

At a later time Walter Cannon introduced the term homeostasis to describe the regulation and adjustment of vital functions so that a steady state exists not only in the blood and tissue fluid but in other bodily mechanisms (*see* HOMEOSTASIS) J Barcroft has more recently argued that the free life is to be thought of as a free mental life since it is the cells of the nervous system which above those of all other tissues require constancy in their milieu

Such conceptions must properly be considered as the highest level in general physiological thinking They are broad generalizations which permit better interpretation of whole series of vital phenomena in many organs It is unwise to accept any definition of general physiology which makes it synonymous with cell physiology as M Verworn has done The study of individual cells is an important part of its field but integrative thinking about the whole organism is its even higher responsibility Research and theory must proceed at all levels

One further example of high level thinking in general physiology may be considered Lawrence J Henderson in 1913 wrote persuasively concerning the fitness of the environment He argued that the physical and chemical characteristics of the inorganic world are peculiarly adapted to sustain life and possibly caused its appearance in the first place His argument may be briefly summarized as follows

Enormous quantities of carbon hydrogen and oxygen partly in the form of water and carbonic acid are apparently inevitable constituents of the atmospheres and crusts of the larger planets The known compounds of carbon and hydrogen and of carbon hydrogen and oxygen far surpass in number the compounds of any other elements These elements therefore are uniquely fitted to be the stuff of which life is formed and of the environment in which it exists Water has a high specific heat Therefore in the ocean depths there are only minor fluctuations of temperature Ocean water carries with it everywhere a constant mixture of

late the flagell t s t th algae Th y h e one flagellum (*P d mon*) two (*Chlamydomo as*) f u (*Ca te a*) (Fig 1) r e ght (*P lybleph d*) Pl ral fl g ll a e lly qu l The gr up la g d ab ut ne f u th f the appr x m t ly 100 ge a f rm palmell id r de dr id col (*T i po* Chlo ng m) with flagella nly in rep od cti e cell C ll w ll a e of cellu l e a d olt n th y a e th k Chr mat ph e on ta n the me hlo ophyll s h gh r pla ts Pyr n ds h ve the us ll form comm ly f d w th t r h th e ers m te al

Un ll l p c e p edom nate but t lea t 16 g n ra f m e l n s The a e t reg f r h ear fl t r ph r c l *F l o gl b to s* h ll w ph r ft n I mm i d amete It m c l g n us p iph y ntain th u nd of b fl gellate zooids Som zoo d are g n d a that fo m new of es a lly by a compl c t d m lt ple d vi ion I og amy the p duct f l ke g mete wh ch fu e, i e m n i Phyt m ad da b t *l It x gl bato* is monoe i od cing l rge egg fs m c tts oo ds a d p ck t of mall p rm fr m th r Eg l b rated into the holl w phere a e f rt l ed by p rm Thi k ro gh wall vel p th fe t l z d wh h e e t lly p du ew c l n e Thu *I gl b to* llu t at s e ual epr d ct n mp r ble to th t l h ghe a *ma*) M t phy *tomo ads* a e f e h w ter i h bitants ome are ter m t l m m tin Se PHYTOMASTICOPHORFA REPRODUCTION ANIMAL [J B L.]

Piciformes

A rd f bi d nt in g x f mil wh h h n mm n a p c l a arrangeme t f the t d of th t d other o r m l ha a t All f m l t i h le a d th you g l rds p d a l u ly l g p d n th n t The l rg t f m lv i the Pi ida th w odpe k s ld id i d t ibuti n ex ept for M d gas r A t la nd m t (O a W dp k r h w m n d pt m d fi at n elat d to the l mb ng d fe d g h b ts tabl the x epti o lly l g t gu d hy d m) m Thr f m l a l ed to th Ne t p l g n the j ca ma (C lb l d e) p ff b rd (Bu c da) d t a (R mph i d) Th b bets (Capit i d) p t p l wh s th h n y g d (I t t d) fin d t th Afr n and I d n g Th h n y g d s n t d fo th h b t f l d g m n d oth n m l t b e i mi roo ga i m th d g t t t pe m t th b d t d g t b w x Ho e g de a e p r t Th y l y eggs t the h l e ts f s h b d a b bet woodp k a d t l ng Se AVES [K C P]

Pickerel

A m ppl d m wh t t l g ably to fi f th p f fi h th g *E* An the mm ly ed n m l r the e p i p ke Th th peci th m ky m kell ng *E x* m q gy All h l ng t th f m ly E ocida

( ) Th nth m pk E o l l gth t r 4 ft (b) Th m k llu g E m q o gy le gth t 8 ft (F m E L P lme F ldb k of N t l H tory *M G aw-Hll 1949*)

The p ke are ll larctic in their di tri uti n One s e e *Es x e ch* t ccurs onl in Siberi The northern pike *E l us* f nd in th n thern p rt of North Amer ca and in Eura ia is one f the fine t port fi h triki g with ferocity and fight ng with determinat on when hook d It fre quently weighs 15 lb or m r Like all the *Esox* la ge e o gh t t it is a xcellent food fi h There is a ub t nt al comm rc al fi l ery fo th pe e prima ly i the Ca d a lake

The mu k llu ge i p ma ly a f h f the Great Lak dr n ge y tem Ther is a ub p es i the Oh o Ri r sy t m S ty lb m kies are taken almo t e y year and 40-lb fi h are fa rly com mon Th s i the ackn wledged king of Ame ic n f e h wate p rt fi hes

The ha p cke l *Esox n ge* i e stern pe es f i l omm in w edy water fr m Main to Fl da It al o occ rs n the ast rn part of th Gr t Lak sy tem and n rthw d up th M pp R e t M s o ri Th s i a maller fi h tha the no the n p ke r h ng a length of only 2 ft Th b nded p ker l *E me can s* r ea t f th All ghen es It s eld m ver 1 ft in length Th malle t f ll the m d pickerel *E t rm latu* ld m n a hing 1 ft in l ngth nd mm n i the M s ippi Oh n d Gre t Lak s y tem

All p ke a v aci u p dat rs n cognized by the d k b ll h d the cyl drical b d and the m ll p t i rly et d r al and a l fins S CLUPEIFORMES [J D B]

Picrate

On f tw type f mp nd wh ch are de i ed f m n rc d 46t tr phe ol The l yd o g n the —OH group f th ph nol i uffi tly labl t t a an a d ad f m s lts w th i or g n c ba the u al ma n (fo e ample od m p t)

Th nd l f p t i gr p ol m l cu l r mpl es f rmed when p cr c a d nd aro m t omp u d s h as aphth l n all wed i e t Alth gh the atu f the ompl e n t e t r lv u de t d they a u ful th d ntifi t of r m t mp nd b c u th

been discovered It is now known that many living membranes consist of two molecular sheets whose thickness can be measured The pores imagined by general physiologists have now been hown to ex ist The molecular architecture of nerve and mus cle cells has been partially explored The intricate ultrastructure of the neuromyal junction has been revealed *See* NEUROPHYSIOLOGY

At the cellular and sul cellular levels general physiology is thus presented with new opportuni ties and a great challenge Older techniques are inadequate to study structures which can be een only in ultrathin sections and which in the cour e of their preparation for electromicroscopy become completely dry New approaches to basic problems mu t be developed combining phy ical chemical and histological techniques in a concerted effort to obtain till deeper insights into vital mechani ms *See* ANIMAL GROWTH CIRCULATION EXCRETION METABOLISM [W R A]

Bibliography W M Bayli *Principles of General Physiology* 4th ed 1927 C Bernard *An Introduction to the Study of Experimental Medicine* (1865) H C Greene s translation 1927 H Davson *A Textbook of General Physiology* 1951 L V Heilbrunn *Dynamics of Living Protoplasm* 1956 L V Heilbrunn *General Physiology* 3d ed 1952 R Hober et al *Physical Chemistry of Cells and Tissues* 1945 B T Scheer *Gene al Physiology* 1953

Phytomastigophorea

A class of the subphylum Flagellata also known as the Phytomastigina The e are the plant flagellates which contain chlorophyll and other pigment bi t also include colorle s forms Gra s green is the usually ob er ed color primarily becau e the green flagellates are the largest Those containing an ex cess of yellow p gments generally are smaller in size and fewer species have unusual colors such a blue or red Holophytic saprophytic and holozoic modes of nutrit on occur a d specific chem cal components may be demanded by individual spe cies within the group

Encystment is frequent among phytoflagellates cyst composition being one method of determin ing relationships for some colorless species Repro duction may occur within the cyst or while the organism is active Gamete formation is largely re stricted to Phytomonadina but l fe cycles may n clude an alternation of flagellate with palmella r with amebo d generations The Phytomastigophorea include ix groups usually considered to be orders These are the Chrysomonadida Cryptom nadida Phytomonadida Euglenida Chloromonadida a d Dinoflagellida See articles on these gr up *S e also* MASTICOPHORA [J B L]

Phytomonadida

An order of the class Phytomastigophorea The pro tozoans also known as the Phytomonadina are grass green but a few are colorless (*Polytoma*) Indi idual cells may be as small as 8 μ They cl ely

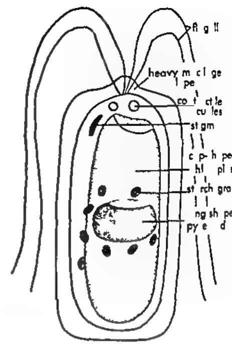


Fig 1 Cart a near tat ca

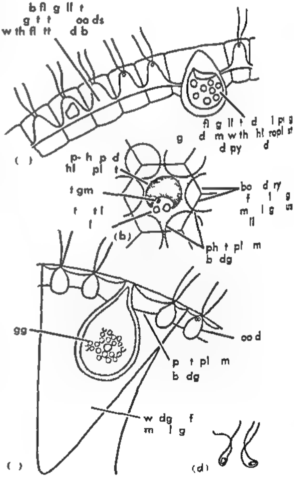
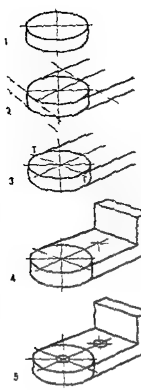


Fig II (a) V I gl bat S t o I w (b) V globat S f e v w f a gl d (c) V II S t I w Th z o ds p a h p d d t t ch d by th adl k p topl m t a d t ch oth Th m clag d w way f om th th k te bo d ry b t af II a po at d to a d p w dg f m l g (d) V a Spe m l g d b t 8 t m by c mp w th ( )



O 11 f n llp t d pct c l
; J H d d A S P lm l e G m try F
g D w g 4th d M G w-H ll 1958)

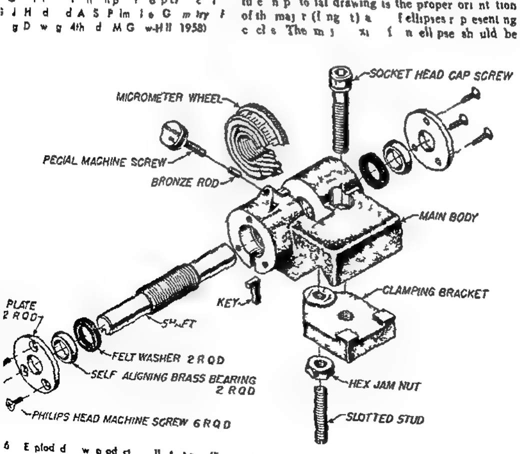
te l to convey id a to th ir si tants and clients

I making a p ct rial draw ng it is important t ele t if v ew ng directio that sh w the ol ject nd it details t the l est ad antage The res iltant drawing is orthogr ph c if the viewing rays are c n d r d as pa allel o Jerspective if the rav re c n dered as meet ng at th eye of the b- s rver Making per pe t d awi g with in tru ments is time- nsuming and requires c ns derabl knowledge nd skill

Several types f no pe spective pictorial i ws can l e sketched or drawn w th in trum nts (Fig 1) The d metric and trimetri drawing pro- v de q ite sati f ct ry iew of the l ject wh le the is metric view is not qu te o satisfactory b cau e f th di t rtion c e ted by the l igh iewing angle H wever isometric drawi g are rel tively ea y to make w th draw ng in truments They re particul rly usef l for sh w ng piping layouts (Fig 2)

Cabinet and other obl q e dr w ngs while not tr e orthographic v ews offer a co v e ent method for draw ng ircles and other curves n the r true h pe (Fig 3)

An effecti e p cto ial sketch of an object can be made if pr p r tt ntion is given to v ewing di ec ti n p po ti n rie tation of ellipses and loca ti n of ta g nt poi t (Fig 4) An s ential fea tu e n p to ial drawing is the proper ori nt tion of th maj r (l ng t) a f ellipses r p esent ng c cl s The m j xi f n ell pse sh uld be

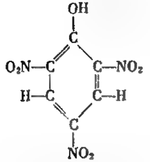


6 E plod d w p od ct ll t to (F m
E g g D w g 2d d McG w
1958)

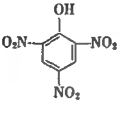
complexes are solids with characteristic melting points These complexes are usually highly colored *See* PICRIC ACID [F E WR]

Picric acid

A phenol in which nitro (NO) groups are present in the 2 4 and 6 positions on the ring of carbon atoms It approaches the mineral acids in acid



Graphic formula



Simplified formula

strength (pK = 0 80) It is produced (1) by nitration of chlorobenzene to the dinitro derivative hydrolysis of the latter followed by another nitration

$$C_6H_5Cl \xrightarrow[H_2SO]{HNO} 2\ 4\ (O_2N)_2C_6H_3Cl \xrightarrow[N\ {}_2CO]{H\ O}$$

$$2\ 4\ (O_2N)_2C_6H_3OH \xrightarrow[H_2SO]{HNO} 2\ 4\ 6\ (O_2N)_3C_6H_2OH$$

or (2) by sulfonation of phenol followed by nitration

$$C_6H_5OH \xrightarrow{H\ SO} 2\ 4\ (HO_3S)_2C_6H_3OH \xrightarrow{HNO}$$

$$2\ 4\ 6\ (O_2N)_3C_6H_2OH$$

It has been used in treatment of burns as an explosive and as a yellow dye *See* NITROBENZENE PHENOL [R B C]

Picrite

The term picrite has been used with several different meanings It is generally considered to include certain medium to fine-grained igneous rocks composed chiefly of olivine with smaller amounts of pyroxene hornblende and plag ocla e feldspar (labradorite)

The feldspar content is slightly higher than that of peridotite and lower than that of gabbro Certain analcite bearing types associated with teschenite have al o been included under the term picrite A characteri tic feature i po kil ti texture in which large pyroxene or hornblende c ystal enclose numerous small grains of olivine

Picrite is rare and is found in small intrusi es (sills and dike) It may also occur in the lower portions of ba altic lava flows whe e olivine and pyroxene crystals have accumulated under the influence of gravity *See* GABBRO IGNEOUS ROCKS PERIDOTITE [C A CA]

Pictorial drawing

A pictorial drawing hows a view of an object (actual or imagined) as it would be een by an observer who looks at the bject either in a chosen direction or from a elected point of view One uch view usually suffices to give the reader a clear picture of the hape and details of the object. Pictorial sketches often are more readily made and more clearly understood than are front top and ide views of an object (*see* DESCRIPTIVE GEOMETRY ENGINEERING DRAWING) Pictorial drawing either sketched freehand or made with drawin instruments are frequently used by engineers and archi

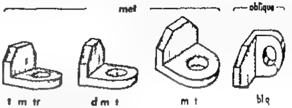
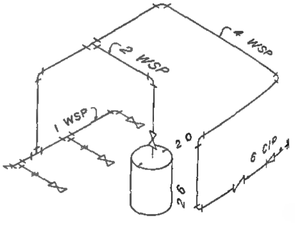
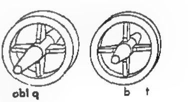


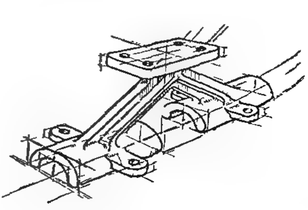
Fig 1 Four different forms of p cto l d aw g (From T E F ench a d C J V rck G ph c S M Graw H ll 1958)



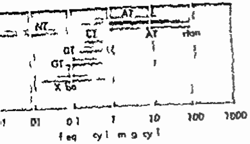
Fg 2 Isomet ic p pi g d aw g



Fg 3 Obl q e a d cab net d w ng (F om T E F e h a d C J V ck G ph Sc e ce McG w H ll 1958)



Fg 4 A pe p ct k tch (F m T E F h d C J V r k A Ma l f E g g D aw g fo St d ts a d D aft m w H ll



g 3 F q cy g f o cry t l ts

El t des m y be ppl d d ctly t the ur e f the c y tal th y may b m nted e t r all l p x m ty to th quartz el ment. ry tal w th lectrod n th s urfa i e tly m unt d by me s of wi wh h m y l pro de the e ti t th le tr d C n r f y t l may b he m t c lly ealed f te ti n f m tm sphe ic effect a d me y t ls a e m nt d n a u te} nvel p to m e Q ndr d e a i g d ft Ex mpl s l m d n a mm nted q art c y t ls a hown n Fg 1 V ummo nt d ry tal ot ap ble f h ndl g m h pow (s ally le tha 1 r 2 m ll w tt m x im m d pat n) Th for l d cry t l f powe cillat r a e i suall m ted i ert g s h n t g h li m

The cry t l r t ut h e f a g ap pl t lly i l t t d b the f q en y t h h th y t l m t op t and th temp a t re a g wh h the ry t l mu t w rk A pl t of typ l f q u mp atu r f l d ff e t ry tal ut h w in Fig 2 A h t f f q e cy nges er d by d ly u d t l t h wn F g 3

Appl cations Q art y t l e n t r m d f t b l i g th f j l ll t s The deg f t b l ti n d p d n sev ral f t rs the p n ipal s b g th Q of the re nato th typ f ry tal ut d a d t mpe t ang of p ati n the typ f t ed nd the amount l p w d p ted the t Therm t t n ft n d t nh n o c ll t r tab l t The ppl t f q tz tal f ll t t b l t o h m de p tbl ur m d m d nd t l i n b d t g d try d m b l d mmu t ns w th a t r ft nd gr u d h l S O CILLATOR

Q t ry tal at n e al o ed t l t w f qu n y s p t o filt r M ny th d f h ry tal a e ed t leph t m f a f q e cy p ati n d t d mmu i at q pm nt f r l t ng a d ed g l l q y b d wh l r t ng d ed f q S FIL ELECTRIC F d g p zo le t t l m nt ar ed f t g b t o t lectri al g ls nd ed h ppl c t a c y t l m ph ph gr ph p kup b t p k up nd dy m p g l m t Th

t er e piez el ctri effect i ed f r c nverting l ctrical ignals i to mechanical vibrati n Th u piezoelectric tran lucers are u d in u h appl ca t on a derwater und rang ng equij ment (d) a d in ultra onic cl ani g de ice wh ch u e a l quid m d um f r wa h g mall to m d i m ized l ject [F D L]

Bibl ogr phy W C C dy *P e o l ctricity* 1946 P A H t ing *Q rt Crystal fo El trical Ci c its—Th i De ign and Man f ctt* 1946 W P Ma o *Pi o le tric Crystals nd Their Ap pl cat n t Ult aso cs* 1950 W P Ma on *Phys cal Ac ti s a d th Prop rt s of Sol ds* 1958 P Vigcure x a d C F Booth *Quart l ib at rs nd Th Appl c ti ns* 1950

Piezoelectricity

Electri ty o ele tri pol rity re ulting from th appli at on of mech n cal pre t e on a d l ctric c y tal The appl cat f a m hani al t e produc s in certain dielectric (el ct cally non c nd ct g) c y t ls an el t ic pol rizat n (elec tr c dipole m me t per c bic centimet r) wh ch i pr po t n l to th s t e Se POLARIZATION (DIELECTRICS) If the ry tal i ol ted this polari zatio man fe t it lf as a ltage a r the cry tal a d if th c y t l h t ir uited fl w l ch [redacted] ea be ob erv d dur ng load ng Co ely appl t of a lt ge bet ee ta n f ces of th cry t l p d es mech nical di tort f the m t al Th r p al rel t n h p i fe red to as th pi el tr c eff t The phe omenon of g n t f ltag u der m ch ical t s l refer ed t s th di t p ezoel ctr c eff ct and the mecha ical st ain p d d n th cr tal un de el ct st e a called the con er e p oelec tr c ffe t

P oel t ic mat ls e u ed e t n t ely tran d e s f n rt ng me h n c l t ain into n l ctr l l S h device n l de m ro phon ph n g ph p kup b at en ing el em nt a d the l ke The co e se eff t n which a me h al output i d i ed from a el tr c l s gnal nput al o w dely s d in t ch de ic as s n e a d ult a tran du l e dpho es l d sp akers nd c tti g he ds f di k r ord ng Both th d re t d con e e eff t e empl y d n dev s h h the m h n al re na ce fre qu nc f th rystal of mp rta c Such d i es n l de el tr a filte s a d f equency c tr l el m nt n l tr n c s illato ci cuits [redacted] ddit n l i f m t o on appl t s e PIEZO LECTRIC CRYSTAL e al DISK RECORD- I C MI ROPHO E TRANSDUCER UNDERWATER ULTRASO ICS

Necessary condition Th n c s y c ndit n f r the p e o l ct c ff ct is th l enc of ce t r f ym t y in th ystal st uct re Of the 32 rystal l s s (s CRYSTALLOGRA HY) 21 l k a c t r of ymmet y a d w il th pt on f on l s ll f the e a e p ez el t i In th y tal l s f l w st ymmetry any type of t e g n r t s a el tr p l t n whe e i ry tals of

drawn perpendicular to the axis of the circle (Fig 5) The major axis of an ellipse representing a horizontal circle is horizontal because it is perpendicular to the vertical axis of the circle

Shaded exploded view production illustrations greatly facilitate the learning process in assembly of machines and devices (Fig 6) When this type of illustration is used the initial assembly of parts into a machine has been found to be three or four times faster than if a conventional assembly drawing is used [ASP CJB]

Pier

A wharf projecting perpendicularly or obliquely from shore serving as berths for ships loading and discharging passengers and cargo Construction usually takes the form of a pile supported platform using steel timber and concrete materials Sometimes quay wall or bulkhead construction is used around the periphery with earth fill inside Piers may be open deck or housed over with sheds They may also have special cargo handling equipment thereon such as that used for loading iron ore Uses of piers sometime extend to recreational purposes such as fishing piers or to community purposes such as car parking Spaces between adjacent piers are called slips *See* COASTAL ENGINEERING WHARF [EJQ]

Piezoelectric crystal

A crystalline substance which exhibits the piezoelectric effect This pressure electricity was first positively identified by the Curies in 1880 when they discovered that some crystals produced electric charges on parts of their surface when the crystals were compressed in particular directions the charge disappearing when the pressure was removed It was later discovered that these crystals become strained when subjected to electric fields the piezoelectric deformation is directly proportional to the field and it reverses in sign as the sign of the field is reversed The elastic properties of piezoelectric crystals are used in electromechanical transducers such as ultrasonic generators microphones phonograph pickups and electromechanical resonators such as the frequency controlling quartz crystals *See* PIEZOELECTRICITY

Piezoelectric materials The principal piezoelectric materials used commercially are crystalline quartz and Rochelle salt although the latter is being superseded by other materials such as barium titanate Quartz has the important qualities of being a completely oxidized compound (silicon dioxide) and is almost insoluble in water Therefore it is chemically stable against changes occurring with time It also has low internal losses when used as a vibrator Rochelle salt has a large piezoelectric effect and is thus useful in acoustical and vibrational devices where sensitivity is necessary but it decomposes at high temperatures (55 C) and requires protection against moisture Barium titanate provides lower sensitivity but greater immunity to temperature and humidity effects Other

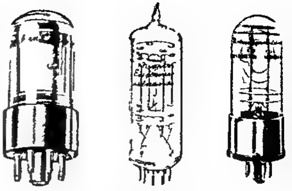


Fig 1 Typical vacuum mounted quartz resonators (Northern Engineering Laboratories)

crystals that have been used for piezoelectric devices include tourmaline ammonium dihydrogen phosphate (ADP) and ethylenediamine tartrate (EDT) *See* BARIUM TITANATE QUARTZ ROCHELLE SALT

The quartz crystal resonator is the most important class of piezoelectric device Its principal application is in the field of frequency control and electric wave filters It is also used in transducers especially where heat or moisture are factors

Characteristics and manufacture The electrical properties of quartz crystals as circuit elements including their temperature coefficient of frequency motional inductance and capacitance series resistance and electrode or shunt capacitance are largely determined by the dimensions and angles of rotation of the resonator surfaces with respect to the crystal axes (*see* CRYSTAL OPTICS) In commercial practice raw quartz crystals are oriented by means of x ray goniometer the required angles of rotation are measured on the mounting jig and the required blanks (unfinished slabs) cut from the mother crystal by diamond faced saws The blanks are then ground to the required frequency using lapping techniques with graduated sizes of abrasives to obtain a smooth finish Some high quality crystals are given optically polished surfaces It is common practice to etch the surface of the crystal with fluorine compounds to remove microscopic surface irregularities

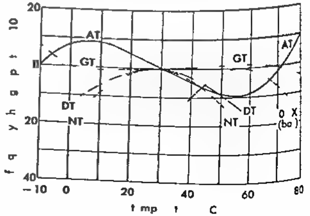
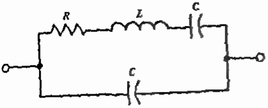


Fig 2 Crystal f q cy a f ct o of temp t f a o ry t l t



Fg 3 Netw k quiv l t to p lectr r o ot o d t o f q cy

b t a e related by expre i n u l i g the las ti ity tensor c_i^E (fo on tant ele t c field E)

$$e_{mk} = \sum_{l}^{6} d_{ml} c_{lk}^{E}$$

(e ELASTICITY) Altern t f rmulat on are p s ble f e ntr d c s the d l ctric d splace m nt D o v ual zes th imult n ous a tion of lectri l and m h cal tr s s

The umt r f depe de t matr elements d_{ij} depends up n th ymmetry el m nts f the ry t l Fo th lowe t symmetry all matrix el me t re i dependent where s p oelectri l se f h ghe ymmetry an ha e a f w s o e nd p nd nt leme t th m t x (d) Th ma trix t k its s mple t f m af th n tur l ymm try f th ry tal are cho fo the o d n l y t m

Electromechanical coupling Th di ect piezo ele t eff t m kes a cryst l a ge e t r nd th er eff ct makes t a m t r C n equently a p ezoel t cry t l l many p p t e n om m n w th m t g n r t r F e ample th lec t l p p rt e h a the d lectric co st nt d p nd up th m h n c l l ad n s ly the m h n l p p rtie uch th l t n ta t d p d th elect b dary e di t s Th i t m h l n pl ng f t k an b d fin d s f ll ws Suppo e electr d are at t r d t pe le t ry t l a d c n e ted t b ttery Th th at o f the n rgy t ed h n c l f rm t th l t cal e e gy d l e d by th b tt ry q l to k f ng f k anges f m bel w 1% t ab t 30% I qu rtz, fo mpl the pli g i ghly 10% In f r ele t tal k n app h ty n e t t c m t n S FERROELECTRICS

In q rtz, a tr f 1 kg m appl d l ng the d da p d p l r zat o f about × 10- l mb m l g th am xt Con r ly f t fi ld of 100 v lt m pr d s a tr n of bo t 2 × 10 l fer o l t ryst l h Roc lle lt rd KH_2PO d ta ntuf roel t u h NH_4H_2PO (ADP) th f lect be es al rd f mag tud l ger

Molecular theory Q ntitat th o es b ed n th deta l d y t l t t r ry f d Q l tat ly h w r the p zo l tr ff t i d ly und tood f mpl y t l truct r F g l illu t at th f r pa t l r cub c crys t l bl d (ZnS) E ry Zn s po t ely ha ged and is l cated in the center f a regular t trahedron $ABCD$ th corne s of which are the centers of ulf r ion wh ch are neg tively charged Wh n th s system is subjected t a shear stre in the xy plane the edge AB for example is elo gated and the edge CD of the tetrahedr n i e mes l rte Consequently th e edges are no l ger qu alent and the Zn i n will b di placed along the axis, thu gi ing ri e t an electri di pole mom nt The dipole moment ari ing f om dif fe ent ctahedra sum p be au e they all ha e the ame orientati n with re p ct to the axe xyz

An tl er mple type of piezoelect ic structure e co ntered n barium t tanate $BaTiO_3$ as hown i F g 2 Th po iti e Ti i ns ar urr unded by an almo t regul r octahedron of negati e oxygen ion The T o s ar n t in th enter of the o tahedron but m wl at d pla ed al ng the z axi Thi tru tu e already hs *a dipole moment or p nta e* u p la izat in the ab ence of ext rnally ap pl ed stre s It i clear f om Fig 2 that the Ti ion i p hed more off center when the c y tal i m cha cally compres ed n the xy pla e or elon gat d al g The additional p l rizati n a oci at d w th thi def rmati n is the piezoelectric po l r zat on S BARIUM TITANATE.

Piezoelectric ceramics Barium tit n te and a few el ted c mpo nds hav the remark ble prop rty that by mea s of a uffcie tly trong electric field the di ect n of the spont ne us p lari ati n an be sw t hed to any ne of th x y z axe Thi makes it p ible to p odu e polycry t lli e sam ple (c r mi s) wh ch a e p ezoele tr c The elec tr me ha c l c upling f ct rs of su h ceramics a e h ab ut 50%

Piezoelectric resonator The p zo l ctric trai s tl at can be i du d by tat el ct fi ld are e y mall ex ept n e ta n ferr le t Larger t s e be bt ined when a p ez le tr c crys tal i dri en by an altern t ng v lt g th fre qu ncy f whi h equal t me h n cal reso na e fr quency f t e ry tal The v brat ng crystal ea ts back on the r u t th o gh the d t p e ele t ic ffect In th n e of a mechani al es na e th r a tion i eq i alent to the re po e of the netw k h wn in F g 3 p o ided that th se re r onan e f eq ency

$$f_R = 1/(2\pi\sqrt{LC})$$

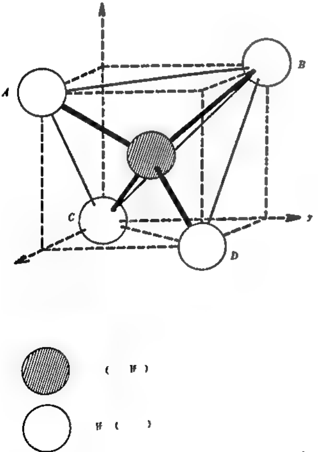
of the n two k i equ l t a me han cal r onance f equ ncy f the cry t l An imp tant differe ce b tween th tw f Fig 3 and the pi lectric t r is th t the latter h s many d crete m de of brat on wherea the netwo k h only ne re na e f eq cy

Netw f m t The el ments L C and C f the eq i lent et o k can b l l ted fr m the phys c l n t nt f th ry tal Co de f r e mpl th simple re nat r h wn F g 4 A ct ng l r ry t l ba w th the dimen ons $l \gg l \gg l$ s ex ited t e mp e al length w e ibr t n Th xy f h adhe nt elec t od and the b r i nted with r pe t t th

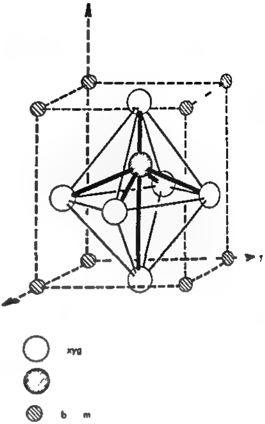
higher symmetry only particular types of stress can produce a piezoelectric polarization For a given crystal the axis of polarization depends upon the type of the stress There is no crystal cla s in which the piezoelectric polarization is confined to a single axis In several crystal clas es however it is con fined to a plane Hydrostatic pressure produces a piezoelectric polarization in the crystals of those 10 classes that show pyroelectricity in addition to piezoelectricity (*see* PYROELECTRICITY) The pyro electric axis is then the axis of polarization

The converse piezoelectric effect is a thermo dynamic con equence of the direct piezoelectric effect When a polarization P is induced in a piezo electric crystal by an externally applied electric field E the crystal suffers a small train S which is proportional to the polarization P In crystals with a normal dielectric behavior the polarization P is proportional to the electric field E and hence the strain is proportional to this field E Superposed upon the piezoelectric strain S is a much smaller strain which is proportional to P (or E) This strain is called the electrostrictive strain It is pre ent in any dielectric *See* ELECTROSTRICTION

Matrix formulation The relation of the six com ponents T_j of the stress tensor (three compres sional components and three shear components) to the three components P_i of the polarization vector can be described by a scheme (matrix) of 18 piezo



Fg 1 Tetr h d al st uctur of z bl nd Z S Only part of the u t c ll i h wn Size of th cl s h s no relat o to th siz of the o s



Fg 2 Un t cell of tetrago al barium t tanate BaTiO₃ De atio f om cubic symmetry s e agge ated S e of the c cle has no relat on to the s of the io s

electric moduli d The same cheme (d_{ij}) al o re lates the three components E of the electric field to the six components S_j of the strain

		Compression			Shear		
		S_1 T_1	S_2 T_2	S_3 T_3	S_4 T_4	S_5 T_5	S_6 T_6
E_1	P_1	d_{11}	d_{12}	d_{13}	d_{14}	d_{15}	d_{16}
E_2	P_2	d_{21}	d_{22}	d_{23}	d_{24}	d_{25}	d_{26}
E_3	P_3	d_{31}	d_{32}	d_{33}	d_{34}	d_{35}	d_{36}

The direct effect is obtained by read ng this scheme in rows

$$P_i = -\sum_{j=1}^{6} d_{ij} T_j \qquad i = 1\ 2\ 3$$

The converse effect is obtained by reading it in col umns

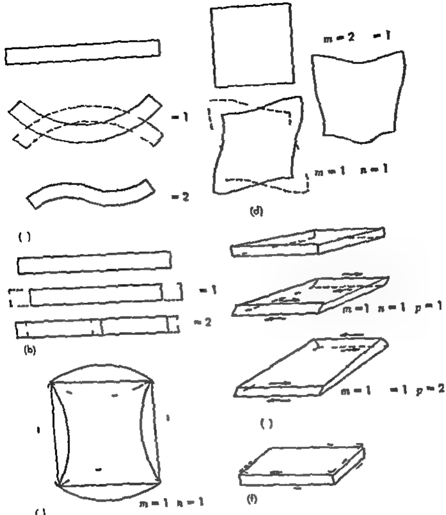
$$S_j = \sum_{i=1}^{3} d_{ij} E_i \qquad j = 1\ 2 \quad 6$$

An analogous matr x (e_{ij}) relates the strain to the polarization and the electric field to the stre

$$P_i = \sum_{j=1}^{6} e_{ij} S_j \qquad i = 1\ 2\ 3$$

$$T_j = -\sum e_{ij} E_i \qquad j = 1\ 2 \quad 6$$

The matrices (d_{ij}) and (e_{ij}) re n t independent



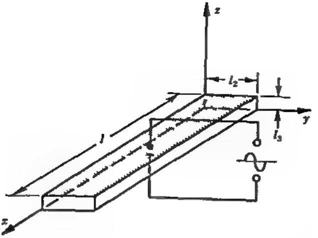
Fg 6 E mpl of b t m d f b d pl t (d) F h b t f pl t ( ) Th k pl t ( ) Fl al b t n f b (b) L g t d l h b t f pl t (f) Th k b at b f b ( ) L g t d l b t n f f pl t

t po ble w th p z lect r mi (B T O typ) be d ff nt p rt f th to n b p l ed d ff e t d t S VIBRATIO

Common applications Th sh rp re a e rv f p el t e at m ke t f l t th t b l zat f the fr q y f d cl l t Q art y t l a d alm t l l ly th ppl at Th ma d a t g f qu rt e h gh Q fa t t b l ty w th e p ct t g g d the p tb lit f o t ng th s t w th esp t t th m f c y tal m that th t m p tu m t f th eso n e fr q y h th m t g t mp t F g e 8 ll tr t th i t n f mm ly ed t nd F g 9 h th t mp t d p nde f th n f q n y f f w f th l a m t b ll t the ry t l g e lly p t f th f db k t l th t p po d by G W P e th d tt s f l l t n t tt f d l the y t l a t e i po t He e th o ll t o f q en y be- l er th es t a d t e n t f q y f

the y t l (ee F g 5) Ci t f this type l ld th f qu ey w th few p ts p m ll on M h gr at r t b l ty a be h eved with the br dge c it f L A M a ham H the ill t on d t n a f lf ll d fo a ph e sh ft in th fe d ba k c t th t at the y t na c f qu ncy of the y t l Lo g t m f q y ta b l ty f b t n p t 10 d ho t term m b l ty of ne p rt 10 m b ach e d w th u h ll tors fo m mple e QUARTZ CLOCK F d t l d nf m t n on the P r e nd M a ham e u ts OSCILLATOR

S lect b d pa filte w th l w l n be b lt by u ng p e le t e t r a rcu t l m nt W th mple n tw k t g f e nat g ry t l ly p s b d f tw the d f f ce b tw n re nt d a t r o a t f e q y e b bt d Fo qu t r n to th s p b nd s ab ut 0 8% At r l t l l w p- ati g f eq n e th ba d t o narrow d comb t ns of c y t l at w th o l d o d o e ge r lly ed A ny thet p e o



Fg 4 S mpl p ezoelect reso ato A voltage applied to the electr des shorte or l ngth ns the bar e ct ng lo g t d l v brat o s

natural crystal axe so that an electric field E_3 along z causes a strain S_1 along the bar according to the equation $S_{1(p\quad)} = d_3 E_3$ A mechanical stress T_1 along the bar causes a strain $S_{1(m\ h)} = s_1{}^{E}T$ where $s\ {}^{E}$ is the elastic compliance meas ured at con tant electric field E_3 The resonance frequency for the fundamental lengthwise com pressional mode is then

$$f_R = 1/(2l_1\sqrt{\rho s_{11}{}^{E}}) \quad \text{cps}$$

where ρ is the density of the crystal The parallel capacitance C is the static capacitance of the crys tal

$$C_0 = \frac{\epsilon l_1 l_2}{4\pi l_3(9 \times 10^{11})} \quad \text{farad}$$

Here is the relative dielectric constant along z For C and L the analy is yields

$$C = \frac{8d_{31}\ l_1 l_2}{\pi\ s_{11}{}^{E} l_3(9 \times 10^{1}\ )} \quad \text{farad}$$

$$L = \frac{\rho(s_{11}{}^{E})^2 l_1 l\ (9 \times 10^{11})}{8d_{31}{}^2 l} \quad \text{henry}$$

(All physical constants are in cgs units) Fo the nth overtone C a d L remain the ame wl erea C mu t be d ided by n The l s e (damping) repre ented by the resista ce R in Fig 3 ari e f example from ultrasonic rad ation friction in the crystal mount internal fricti n in the crystal orig inati n various imperfection and from dielec tric relaxation

At the mecha ical re nance frequency f_R the ac current is maximum and is determined by R At the antire onant frequency

$$f\ = \sqrt{(C\ + C)/LCC_0}$$

the current is minimum The d fference $\Delta f = f_A - f_R$ incr ases with increasing ele tromechanical coupling accordi g to the equation

$$\Delta f \approx 4k\ /-$$

The reactance dep nd upon frequ ncy a shown in Fig 5 For a typical piezoelectric cry tal such as quartz resonating at about 10 cp th following orders of magnitude are typi al for the elements of the equivalent network

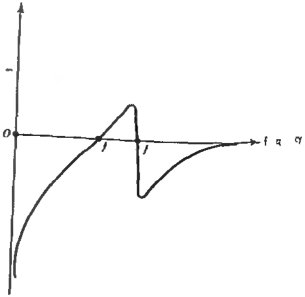
$$L \approx 10 \quad \text{henry}$$
$$C \approx 2 \times 10^{-14} \quad \text{farad}$$
$$C_0 \approx 5 \times 10^{-12} \quad \text{farad}$$

The damping resistance R varies from about 10 to 10 ohms that is the Q factors

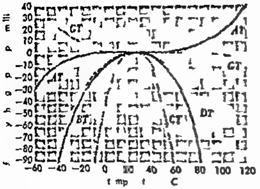
$$Q = \frac{1}{R}\sqrt{\frac{L}{C}}$$

are in the range between 10 and 10 and the resonances are very harp The e characteri tic can not be achieved with conventional coils and con densors as circuit element

Vib ation modes With piezoelectric re onat r of various types the range from audio frequencies to many megacycles per second can be co ered The vibration modes frequently u ed are (in order of increa ing frequency) (1) flexural vibrations of bars and plate (2) longitudinal vibration of bars and plates (3) face hear ibrations of plate and (4) thickne s shear vibrations and compre ion vibrations of plates Figure 6 illustrates ome the e modes The excitation of particular vibrati modes can be achieved by proper orientation the resonator with re pect to the natural cry axes by proper po itioning of the electrode by proper mounting A imple example i illu trated by Fig A bar is oriented so that an elec tric field along x cau es an expansion or contrac tion along y The electrodes are plit and cro connected so that the bar flexes in the yz plane when a volt ige is applied The fundamental flex ure mode is easily excited with this arrangement h we er excitation of higher e en numbered flexu ral modes is also pos ible Interesting resonators



Fg 5 acta f q cy fo a p z el ct c o r



Fg 9 T mpe t d p d of th e o e f e q cy of q rtz c t mmo ly d i flte d s ll t rs (F m W P M s P ef t Cryst l d Th Appl t t Ult V N st d 1950)

el t cry tal The m x m m ultr c ten ty th t lly bt i ble n water by mean of q artz mm m d hyd ogen phosph te f th d 2000 watt / m d 200 watt /cm e pe t v ly P ga e the mech m al imp da m t h po that th rre p di g al e a b t 4000 t mes m lle H wev r th me ch c l mp d ce mat b n b g tly mp d b i g pie o le t i d c s n t n f tw d ff tly ted ryst l ts em nted t g the n ch w y that a oltage applied t th l c t od u th eleme ts t deform i pp it d ectio a d a twi t b d act on re It A mbl e f th typ (Bim ph) w th B T O erami r Ro hell lt a e w d ly sed in h dev s mi opho e a ph e a d ph n g ph p kup c tt dg [W K]

B bl g ply W G C dy *P l et ty* 1946 W P M o *P z l et C y tal d Th Appl t n to Ult a* es 1950 J F Nye *Phy l P p ne l C y t l Th Rep t r by Te nd Matri s* 1957

Pigeonite

Th n m n t the m l pyrox of the g eral f rm la (Mg F)S O with m ug te n l d t n P geon t b a the me l t o to th rth h mb pyro e s ug te d t the d p de-hed b g t e e P geon te i th r th l mb py o equ l n the l n ock M t h gh t mp r ture m t m rph and ig neou rth rh mb pyr e e p b bly o g i lly p geo it Th m ll pt ngle (l) d t gu he th m l f m ug t a d the i l n d e tin t d t ng hes t f th th h mb es P geo t f rm bl k b ow r d k g h rt st bb ry t l with th 87 pyr ne (110) le ag s Th slo er cool g rate f th gneou nd m t m rph c ocks lly p m t th a g t m te l n ol t n t e s l e d the e- ma g m ocl i py e to i ert t the th rh mb f m Th r g al aug t m teri l er d t by th ted l t n lam ll e n ll t th h mb pyro n Th f t c ol ng r t of the volcanic rock quenches in the augitic m ter al and thereby pre rves the metastable pi geonite at urfac t mperature *See* ORTHO-RHOMBIC PYROXENE PYROXENE *S e also* AUGITE DIOPSIDE ENSTATITE [C W D]

Pigment

A finely d d d materi l wh ch co trib t s to the opt c l and ther pr pe t es f rface coatings P gments r in ol l le in the ating m t rial as opp sed t dye whi h c l r the c ating by d s ol g m t Pi m nt a e mech n ally mixed with the co t g nd dep ited when the coati g dries Th y are n t in general ch nged in their phy ical p opert s by inc rpo ation in and dep iti n from th ehi le P ment may b cla ifi d ccord ng t th r mp ti n (inorgan c n rga i) or th i u ce (natural n synth ti) Howe er the mo t f l cla ification s by their c l a wh t t a p re t c lo d r by their f i ct n

White pigments Th materi l are e nti lly tra pare t to i bl light l ut bec u e f the dif fe en e in refr ct e i de betwe n the pigm nt particles and the v h le they ef act the light f om a m lt tud f rf ce and ret i a b ta t l port on in th d rectio of illumin ti n with t ignific t ha ge i it spectral composition *See* COLORIMETRY

The mmon wh te pi ment re t tan m diox d deri ed f m tit n m bea ing es wh te le d from the or os n of m tall c lead nc o de f om the b rn ng f zin m t l and l th pone a mixt r of zi c sulfide d ba um sulfat Le s omm nly p r c ulfide nd antim ny xid sed Tit n m d ox d m y be ry tallized in the ut l the nata form depending upo the method of pr du ti It may b m d fied i ther by rfa e tr atment to contr l th r te of halk g d th p opert es Rut le t tan m di xide has a h gher ref ct e d x than anatase a d the for high r h di powe b it t ha a ome-wh t y llow lo Anat gi a pu er wh t

Wh te le d m y b b sic rb nat of le d made by rr si n f m t ll c le d by cetic or im l r a ids r ba lf te white lead made l y s bl mi g l d s u d co t ll d *cond t ons* The tw p gm nts are l rg ly nte ch ngeabl Re- c tly b ic il f l d has be m de a l abl g g th ame result with a somewh t low lead ont t Wh te l d gments the old t f the wh te gme t d ar d i exte i pa t to wh h th y c ntribute e t ued flex b l tv d du b bt

Z x de is c mm nly m d l y bl m t n f met ll zi c n th p f a r If l ad on ta ng o ed lead d zi d obt ined th l ad b ng n the f m of b le d s lfate Z d ry t r t l e a d shape accord g to the inte ded e Zin x de film ha d and br ttl nd the p gme t ra ly the le p g ment n a c at ng A erta am unt i u lly Z x d w f m y yea s th p inc pal

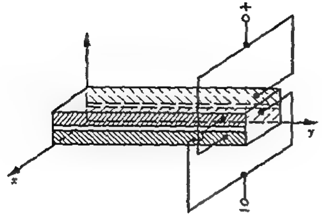


Fig 7 Exc tat o of a fle u e mode by means of split elect odes

electric cry tal which is often sub titu ed quartz in this particular application is ethyl diamine tartrate

Piezoele tric crystals provide the mo t co ie ient means for generation and dete tion of vib tions in gase liquids and solid at frequenci above 10 cps Quartz, ammonium dihydrog phosphate Rochelle salt and barium titanate a frequently u ed in sonic and ultra onic tran du ers The mechanical impedances of liquid and s ids are generally clo e enough to the mechanic impedance of the piezoelectric crystal so that eff cient energy transfer is pos ible The inten ity c ultra onic radiation that can be achieved is mainl limited by the mechanical strength of the piez

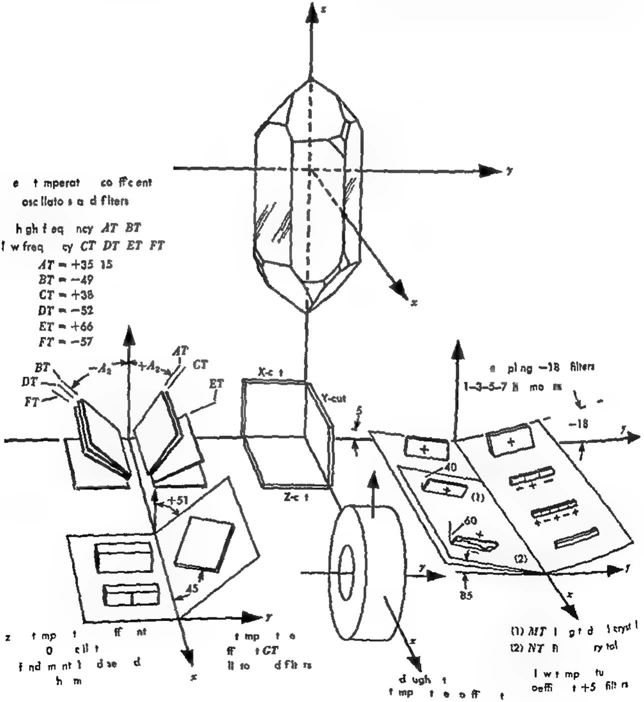


Fig E O ntat w th e pect to the nat l cry tal a es of som of th m e commo ly sed sp c l c t of q artz (F om W P Ma on P z l ct c C yst l and The Appl at on to Ult a s Va Nost a d 1950)

Co r e mat ial h a pum are oft n dd d whe a n l ppery at n is r q red Gla b d e a ery high d gree f r fra ti ity in th di e t on f llumination and are often u d in nt r l ne pa nt f r son wh re n lt ibl ty r qu d Int me c nt pi me t puff up un der h at g g a nsulat ng c t g wh ch r t fi Se COLO DYE PAI T SURFACE COATING [F S H]

Bibl g phy W V n Fi her (ed) *Paint and Va h T h logy* 1948

Pigmentation

Th mal lo of th b dy nd it o g n e its fr m a umm t n f the tu al c l r of the t the p gme ts d p ited the ein and the p g ment ca i d thr gh i th bl od bath ng it Of th p gme ts p ent i th k and hair melanin m t import t whil hemogl b in its reduced a d d ed f m the m t imp rt nt bl od b e p gm t S e C I BON TOPHORE

Melanin Th a p gment pr ent a sc p e o bm r p l wn o ll k gr n le th ll f the p rb al lay r f th k a o ally in th nde l g d mi m th l i and n th i It ppea t b l alized in the m t ho d a d a polyme f y l ga i p nds d ri ed f m th am n ac d tyr ine by th a i n f th me t a The effe t f mel n kin l d p d not only n it l t ol l t l n i al l ty i tte d t l ght The b gl i l of the pe e m f b b f ample a a e lt f the cat t ng f l ght f m d rk p gme t g a les n fie t al ar ngement

Th m t f mel n th sk w th n de l m t f om p t p n f m e t within memb f a g e to h a d f m t t i th body n dd t n t h in b t t t ch n when t mul t d by a a et f f e Th da k of f th egr d kin du t th o t t n f el nin n th k n the da k l of th eyelid n ppl a d g n t l a n C n ta h e a tly th me au Exp ur to ltr l t a unl ght t oth n is g ad t n in a in th m u t f m lan n p t th k n

Th l f th ha d p d the el t hip f th m t nd e l at n f p m t a d the d rk th l a the m e p gm t a d le Th gra t wh s h f ld ag ont s l m t mel n

Control of pigmentation I m ny n m ls pr b bl l d g m mm l p m ntat n at lea t t m t nt nt ll d by h m n tabl p t a ro h rm ne f th p t t ry gl nd k n a m la t r m l t ng h rm n (MSH) Th l m n t r m l r h mo l wh ch ha a t k ng ff t n kin l n amphib ns a d f h p es m ll pl y p rt n th g n ral d el ang f gm t t n h h mp y me nd t m a d by h rm n l amb lan e In th e condition th re may be a direct or indirect influ e e on MSH produ tion Oth r c dit n a ci at d w th variat ons n the t r id ex h m ne and of the thyroid hormo are al o a ociated w th change in kin pigm ntation

An th r p ible controlling force o r kin pig m ntation i the nervous y tem The cell which p duc mel nin m the body hav the ame em bry logical der vati n as ne ou t ue and ind r t e id nce ugge ts that there i some neural ont ol o r these cell

Th ba i pattern of pigmentation i of c i r e h r d t rily dete mined and me ab n rmality of p gmentation h e im l he editary l a i

Focal abnormalities In m lan n p gment ti n focal bnorm lit e incl de the familiar f eckle a d the da k kin blemishes kn wn a m le or n The e l on r flect f cal x e i e dep tion of melan and th y are entirely benign b it a malign nt c unterpart exi t in the malignant mel anom wh ch appears to c me ab ut as wild un on tr lled o rgr wth of th m la n prod icing cells Foc l p t of hyp rpigmentat on al ccur c m monly i e pon e t inflammat n o irritat on Am ng the f cal ab rmalit es are the irregular p t he f d p gme tat on occa n lly p e ent from bi th (l ukod rm) r a i ng later in l fe as r lt f infe t on tr uma r ome unknown a e (til go) Spots f hyp rpigm ntation of ary ng and hap s occu in njun t on w th ch a i d d ea s as polyo t ti fibr u dyspl ia (a d s of b with an as o iat d endo rine bn mal ty) ne ofibromato (multipl w de p ad be ign tum r of neural rigin) ntestinal polyp s (a h ritable condition ha acte ized by mult pl p lyp of th inte t e) and in a o ia ti n w th rous nte n l mal g a t tum rs

Generalized abnormalities In extern l melan n p gment ti n aff ct g th e ti e b dy u f e g ne liz d abnorm l tie r not uncommon The mplete part al abs n e of melan n found in lbin t an inbo n d s der inh t d a Me d lian r ce ve o n m ld ca as an irregular d m nant au ed by th l ck of the enzyme ty sin as wh h n c ry t co vert ty sine to mel anin The l k f pigme tati n in th eye l th se ubjects s comm nl a oc ated w th oc l d ffi lt s l phenylpy ic olig ph a rare e i inb rn di der chara ter ed by mental defic n y th e s lack f ty in b c u e th enzym ce ry t c n ert th am no a d ph n ylala e t ty la k ng a d although ty na i n t d m n sh d th u ual amount of m l an not be f rm d The pat ent is therefo e p le

Ge ral z d hyp rp gme tat n c r n ad e- n l hyp f nct on (Addi on s di ea) b bly d tly th ugh eff t MSH wh l hypo- pituitari m cau s hyp p gm t t bec e MSH produ t on pp d the under t e tu tary gland Th h ng m p gment ti n f th n pple a d th r a in p egn ncy well

white pigment of interior paints but has been largely superseded by titanium dioxide

Lithopone is the pigment which results when solutions of barium sulfide and zinc sulfate are mixed precipitating zinc sulfide and barium sulfate both of which are water insoluble The pigment contains about 30% zinc sulfide which is responsible for the hiding power Although large amounts of this pigment were made and used in past years it too has been largely superseded by titanium dioxide

Pure zinc sulfide has a refractive index almost as high as that of titanium dioxide It has however almost no advantages over titanium dioxide and is not widely used

Antimony oxide is occasionally used in enamels but is most commonly found as an ingredient of certain fire retardant paints

Transparent pigments The refractive indexes of these pigments are very close to the index of the paint vehicle (about 1 54) They are used to provide bulk to control settling and to contribute to durability hardness and abrasion resistance They are often referred to as inert pigments which is in error because some are extremely reactive Because one of their common uses is to add bulk to other pigments they are often called extenders Most transparent pigments are natural minerals reduced to pigment particle size Among the most commonly used are calcium carbonate (ground limestone whiting or chalk) magnesium silicate clay silica or barytes (barium sulfate) Barium carbonate and other minerals are sometimes used Precipitated barium sulfate (blanc fixe) or calcium carbonate are sometimes available often as by product of some chemical operation Transparent pigments often constitute a substantial portion of a protective coating

Colored pigments These pigments are available in a wide variety of colors and properties depending upon the end use Several hundred have been used at one time or another but the following are most common

Red Iron oxides often classified by color include Indian red Spanish red Persian Gulf red and Venetian red (a mixture of iron oxide and calcium sulfate) Other red pigments include cadmium red (cadmium selenide) and organic reds which are usually coal tar derivatives either precipitated in pigment form (toners) or deposited on a transparent pigment (lakes) Organic reds include toluidines and lithols

Orange Chrome orange (basic lead chromate) molybdate orange (lead chromate molybdate) and various organic toners and lakes are the most common orange pigments

Brown Browns are nearly always iron oxides although certain lakes and toners are used for special purposes

Yellow These pigments include natural iron oxides such as ochre or sienna or synthetic iron oxides which are stronger and brighter chrome yellow (normal lead chromate) cadmium yellow (cadmium sulfide) and organic toners and lakes such as Hansa Yellow and benzidine yellow

Green The most important green pigments are chrome green (a mixture of chrome yellow and Prussian blue) chromium oxide which is duller but more permanent phthalocyanine green which is an organic pigment containing copper and various other organic toners or lakes often precipitated with phosphotungstic or phosphomolybdic acid

Blue The blue pigments include Prussian blue (ferric ferrocyanide sometimes called milori or Chinese blue depending upon the shade) ultramarine an inorganic pigment made by fusing soda sulfur and other materials under controlled conditions phthalocyanine blue an organic pigment containing copper and numerous organic toners and lakes

Purples and violets These are nearly all organic toners or lakes Manganese phosphate is an inorganic purple pigment but is very weak

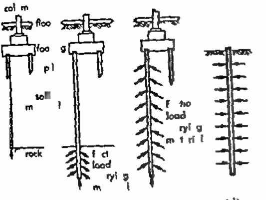
Blacks The vast majority of black pigments consist of finely divided carbon (carbon black lampblack and bone black) usually obtained by allowing a smoky flame to impinge on a cold surface Black iron oxide and certain organic pigments are used where special properties are required

Special pigments Anticorrosive pigments are used to prevent the formation or spread of rust on iron when the metal is exposed by a break in the coating The most common are red lead an oxide of lead and zinc yellow or zinc chromate a basic chromate of zinc Other colored chromates are sometimes used The color of red lead fades rapidly and the anticorrosive chromates are usually very weak in tinting strength Metallic lead is sometimes used for anticorrosive paint

Metallic pigments are small usually flat particles of metal prepared for dispersal in coatings Aluminum is most common because it will leaf and form a smooth metallic film The flakes are sometimes colored Bronze copper lead nickel stainless steel and silver appear occasionally Zinc dust or powdered zinc is used more often because of its excellent adhesion to galvanized iron than because of its appearance

Luminous pigments will radiate visible light when exposed to ultraviolet light Phosphorescent pigments continue to glow for some period after the exciting light has been removed these are usually sulfides of zinc and other materials with small amounts of additives which t l tle ph phorescent pr pe t e Fluore t p gments lo e their luminosity a on as the excit g light i removed the may be sulfide al but many organic pigments ha thi property *See* LUMINOUS PAINT

There are a number of other specialized pigments such as those which change color at some predetermined temperature f r in indicating h t areas on m t pigment to give a pearly appearance and pigments which d ct electricity f p nted circuits



, 1 ll f pl ( ) As e d b g c l m
As f t pl l w p rt ( ) As f ct n pl
ll l gh (d) A omp et f l

nal mat i l through n tabl t ata water or P l may a t a mp to f some type f l th mp vi g t tai n powe

Be r g al e f a p l i th ll w ble o pre-mpti e l d wh li pa ticul r type l ngth and f p l t n spac g c n sta the pec fi g nd onditi n t a t w th t tl ttleme t ed ng n acc ptable am t It de d up the ab l ty f th g nd t e th o d f m th pil i f ti r e d l a g nd upo the ab l ty f th o l t di tr bute th l d n t l a labl e i ta c i m b l d with a ept bl am u t f ettlem t Th soi a m l a part f a fo ndat i th p le a d o l p p m t be n d r d S SOIL MECHANICS

All p le d t b t f ad t the s l n th h pe f o- ll d b lb f p ur wh ch may b sh w by l ect g p t ts of q al t e nte t (F g 2) Wh pl p ng r h th t b lb f r nd d al p le e l p they m g int a l g r b lb t d g t a g ater depth O r lap also lt l g r t it f p e u at ert lev l Th t d t pr di g at r s ttle-me t Settl m t p odu ed by a f m l ad p p t n t th d met f th l ded r f h l b t th h l ttl ffect n h l sol l hes l ettl me t t ue l g p d of t me nd be a e th y a d pe d t upo i te s t e of p e s e ry w th l d d l e ti de the tru t re Th ll wable d ff t l ttl me t hould b e t bl hed n he l

B g ap t e r u lly mp ted by f mul s, th m t c mm n f wh li m the lt m te be ng l t b equ l t the dyn m d i i g f g f t f e gy l i h mme p l a d mp t S h f m l s a p pl bl ly w th h l ol B ng p t e m be est m ted by judgm t a t nt f t al b ed p n h d e f dr g the mpl wh n m k g s l test bo ngs o b l b at ry t t f l mpl s, M t accu ate e lt r btai ed f m fi ld l d g te t n a tu l

p le f om wh cl the allow ble load m determined by d d g the l d at failure by a fact r of afety Load te ts n c fe e n l howe er only te t the h a i g val e f the l or pile fricti n an i g v no indi at n f th i ltim te ettlements

Pile driving Thi is th driving of p le or cas i g or hell to be filled later with con rete l y mpact from pile-dri ing hammer Tl term is sometime loo ely appl ed t the placing of pile by any meth d

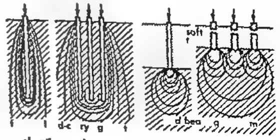
D op hamm r con i t of we ght ra d l y a cable running o er a fram and tend ng l ack t a drum The weight released by a trip the drum i llowed t nw nd rapidly Drop d tanc re su lly l igh Freq ien y f bl ws i l w

Ste m h mme may b of ral type all f whi h requi e the u e of st am l ile or i com press r Single-acting hamm empl y team or compre sed a r to ra the mo able ma which i then t ipp d nd fall by gr v ty alone In the Un ted Stat the m vable ram i i d th ca ng i E rope the ca ng metime th m va l le pa t Cha acteristic f the bl w are a low tr k i g vel city by hea y weight D uble act ng h mm r u e steam or compr s ed air to rai e the t king pa t and l o to imp rt add ti nal ene gy du ing th d wn t k They ri n at gre te p ed th n d s gl a ti g h mme s D fferent al a ting hamme also empl y ste m o a r to e the t ki g p rt a d mpa t ddit al e gy n the down t ok l ut a o d a dr p from the ente ing t am pr ure t m n ff ct e st am p e e

D el h mme s are lf c t ned in t made up of cyl nde pi ton r ram mall fu l t nk a d fu l j t r They we gh l s than steam h mme s a d r q n te m r a r pply They ise small am t f fuel o l

Jett ng co ts of displ ing the il at the p le tip by mean f d charge of quant ty f wat or a thr gh an i t nal n e te al j t pip which al o l h tes the sides f th p l it ri e to ap It m d ne t a d the p le n p ing th o gh h d t ta n t tu t d tably to be l ea g m t l or to bt mb dme t i hard m te l wh h m ght us dam t the p le

J ck g p le d w eq es re ta e to thr t aga nst Th m thod us d i nde p n n ng wh e h t ecti ns f pile re in rted a d



Fg 2 B lb of p d b g pl ( ) F f t pl (b) F

as pigmentation disturbances in eunuchs point to a control either direct or indirect of melanin production by the steroid hormones Melanin deposition in the kin is also increa ed in hemochromato i although part of the pigmentation in this disea ■ is due to the deposition of iron containing blood pigments Certain intoxications notably arsenic poisoning can also lead to generalized hyperpigmentation

Blood borne pigments Of the pigments normally present in the blood stream hemoglobin the oxygen carrying pigment of the red blood cells is the most important in determining skin color Its effect is be t appreciated in the opposite phenomena of blushing and blanching in which an increa ed or decrea ed volume of blood and therefore of hemoglobin perfu es the skin becau e of dilation or constriction of the skin ves el

The red portions of the body the mucous membranes lips and similar structure and the red organs owe their color to the propinquity of blood carrying ve els to the urface Similar pigmentation ■ seen in hemangiomas the so called strawberry marks and imilar skin blemishes in which a local abnormal proliferation of blood vessels occurs close to the kin surface

Qualitati ■ and quantitative changes in circulating hemoglobin are reflected in visible changes in kin color In anemia for instance when there is a decrease in this pigment the body is pale while in polycythemia a condition characterized by increase in circulating red cell the skin ■ ruddy Oxidized hemoglobin that is hemoglob n carrying oxygen from the lungs to the body tissues is bright red while reduced hemoglobin is purplish In condition in which the blood is poorly oxygenated because of di ea ■ of the lungs or heart or through the inability of the blood to circulate to the lungs (so called blue babies) the skin become purple or blue (cyano i) When ca b n monoxide i present in inspired air it combines with hemoglobin to yield a cherry red pigment carboxyhem globin and when certain reducing sub tances are introduced into the blood stream another abnormal hemoglobin product methemogl bin which has a chocolate color is formed The pre ence of these substances in the blood ■ reflected in app opriate changes in kin color

Other pigments may be carried in the blood stream Jaundice a yellowing of the skin is cau ed by the deposition of bile pigments in the skin Carotenemia another form of yellowing of the skin is found in indi idual consuming large quantities of carotene containing fruits and vegetables such as carrots and apricot Small quantities of carotene are normally present in skin and contribute a slightly yellow color to ■ *See* JAUNDICE

Exogenous pigments Finally skin color may be changed by the deposition of entirely foreign substances which may be introduced directly as in tattoos or indirectly through ingestion injection or inhalation as in il er poi oning (argyria) lead poi oning (plumbism) and bismuth poi oning in which the metallic alts themselves are deposited in the skin to cau ■ pigmentation

Other organs While other organs be ides the skin may undergo color change the color chan e are analogous to those een in the skin The ba ic color of an organ is determined by a combination of its fat content (yellow) blood (red or purple) and native pigments (ceroid lipochrome cardiolipin carotene hemo iderin) and by the cattering of light from micro copic and submicroscopi particles The organs may chan e color becau e of increases or decreases in any of the ■ parameter through introduction of foreign ub tance a coal pigments (anthracosis of the lungs) and product of ca cara metabolism (melanosis of the colon) or through accumulation of colored material normally pre ent in minute amounts (alkaptonuri ochrono i) [RBH]

Pile driver

A machine that hammers wood concrete or teel (H beam or pipe) piles or plain or corru ated sheets into oft ground to support tructure to make retaining wall or to keep water or earth out of excavations Drivers are operated from tractors cars that run on rails or barges They con ist basically of a crane boom from which i hun a leader parallel connected guides that fit over the pile and contain the weight or ram a potter or horizontal connector near the ba e that help po ition the leader o er the pile and a control cabin and power source With gra ity pile drivers a weight is inched to the top of the leader and let fall With steam or (since the early 1950) compre ed air dri er the weight ■ ually re t on the pile and the dri ing blows are applied by a wiftly mo ng am In some applications water jet ahead of the pile are used to erode away a path for it making possible the use of a lighter ram or weight [CCO]

Pile foundation

A ub tru ture supported on structural unit introduced nto the g ound to tran mit a load to lo er trata or to alter the physical properties of the ground The suppo ting units called pile are made of wood c ncrete ■ steel

End bearing and friction piles End bearing piles tran fer load from the footing ■ bedrock or ther firm material capable of with tanding the intensity of p essure transmitted by the pile Certa n types f ast in place concrete piles can be formed with an enlarged base which will reduce the intensity of appl ed pre sure and thus permit the u e in end bearing of material of less strength or allow the use of a greate applied load (Fig 1)

Friction piles are dri en into fairly deep beds of soil of s mewhat uniform consi tency They tra sfer their load to the surrounding ground by means of frict on along the length of embedment or by hearing of the closely surrounding oil The full length of the p le may be effecti e ■ friction or the pile may extend of

W d heet p l ng n i t of o two r three h ck e of pla k with ari u type of el e n e t on It l r ly t ed f l lding fo da e a ati n and coff rd m

St el h t pil ng i fo m d f flat ch n l o Z h p d t pr d d with dge int l ck : ctio b v n a wide range of t ength It u d f r fl d m pe r t w ll s- and exca t n

C n t h et pling n i t of pre a t re tan g l o c ete p l w th ed e te lock It i f t n t ed h l w rk S e CAISSON FOUNDA TION Co FER R I RETAINING WALL [R D C]

B bl g phy Se FOUNDATIONS

Pilot production

In ma prod ct n nd t t whe e ompl ated prod t p s eq pme t ar b ng d el p d a y l t pla t ft n l d t th p e entati n of a b tt r p od t t th u t m l wer d lop m t d man f t i t mo e effi ie t fac t ry p at nd e tl r i t d tion f the pr du t F ll n the gi t g d elopme t of a prod t pr r mpl eat d p ece f eq pment nd t n f a k nd f l t at n in th n d l h p it be m d bl d n es ary to t th d vel pment m lat d fa t ry f

Facil ties T ac mpli h th the p l t pl t, a nt rmed t tep b t en l l pme t lab ra t r d p od t n fa t ry i t l l h d It p ded w th p r o nel d la l t e th t d pl ate a n arly p bl tual m n fa t r ng d t b t a f ee of th d to-day n e ty f m t g d l ry wh d le

Th r q r per l who a l g l ly k lled n th fi ld b t t n ly p t Th y m t d r t nd the th k ng a d obj t f de l pm t n n nd m t l p at th da to-d y p ll m that t n f t y p at th n k lled s m k lled n

Ad q at eq pm t a d t h ld be pro-ded to a mmod t th f ll nge f fa t ry re q m t S metim h e e it m y be imp e t l t t d t f l t p l t pla t hec f fl p l m tat n o b u f pec l d ry q d In h g m t h ld be mad t p f th e p l t pl nt fu t n g l p d t n eq pment the f r b r d p l t pla t pers n d fi l t of

Objectives Som f th obj t f p l t pla t p t n f ll w

Q l t l P l t pl nt op t n d m t t th b l t f p q pm nt t f t t th t th d d q l ty le el d fa t y per t g d t

M t l u ag T d tr te n m al g l m t l d g th p l t p at n th m t r al ed f l ld b t l pr t t nd t n th f ll a g f a b l ty p m tted b m t l pu h se pec fi at n

P l b l Pil t l t d m tr t h th th p oces l ed a p t l a d real t c and whether oper t ng p ced ires can l foll wed in the r e tirets by the type f per nnel u d in the fact ry

Eq pm t r l ability To dem n trate the capa bility of the eq ipment to pr duce at pe d and m chine effic ence e wh h will bec me tandard n the fa t ry data a e re orded du ing pil t pro d ct n wh h h w whether th equipment will p rf m t ati f ct y rate of defecti e Pil t plant exper e c e tal l t s a li t of spare parts wh ch w ll b n t ally pro ided t the factory

Pe so n l requi ments Pilot experience stab-l h the amount and labor gr de f producti n and ma ntena e pe el r qu r d t operate the pr c r equ p n nt Th i d n w th th p rati n of indu tr al engine ri g and indu trial relati d partme t

S fety Du ng pilot run the afety departm nt has an pp rt n ty to re iew the pr ce or equ p me t for c mpl an with fety re r rement

Facto y a c pt Perhaps the m t impor tant objecti f a p lot pla t i to aff rd y pre e t t of the fa t ry to whi h the pr ce equipment w ll b t an ferr d an pp rtunity t witne the p r tio nd t gr e th t t eady f r the fa t ry Thu cr t c m of th de l pment m m d a d ts int d ti n into regi la f c tory p ati n mpl h d m re qu kly

M f turing st P lot pla t operation p o-des th ppo t n ty t e ify g n ering t mates f man f tu ng co t nd may ind c t the n ty f pric ng ch ng r for t k g fi ther tep to duce the c t f p d ct i o de to e ch ti f t y l v l of pr fit

D l pme t t The c t of de g ing and d el p g p oce r equipment nd f in tr t n p r n el in their u e t oft o ly fr eti f th t t l o t t v l d n pr d cing a final eff c nt p e r machi e Th debugg g r w k g out f u f eseen p bl m a ume a g eat d al f t me and dd a l rge am u t f e pe e b f r th p ce r m ch n is dy f r fa t ry op ti n The p lot pl nt el e c th fa t y f th xp n f a tr al u b th indr r t c t nd i l t p od ct n of e t bl hed p duct The lo e pro m ty f th pil t operat n t ngin r n d th skill d pe s nn l per t fi st ha d b erv t f op r t n a d q cker d t requ red chang It m y al a e the xpen e and t me of u h p s nn l t a el ng t f t ry l t o nd th et of eq pment f m the fact y t t p t f g

The fina ng of a p l t pl nt h uld l e o a b d t a y b k d f t fac l ti p r l l p t h ld b p ided as p f a man fa t g de l pme t b d Th p l t plant h ld n t b xp cted t fi a e it elf th igh ma fact ed p od ct th rw m nageme t t nd t k p the p j ct n th p l t pl nt lo g th n n e ry n d t ate f d fo t p- at The p l t plant th n f t al a a dev l pment fun t n a d the d d t re t of it p r l to int d c mp y ment a d t ta k l ew r w h

connected after each is jacked down The re ist ance of the pile is mea ured by a gage connected to the jack Thi method avoids vibration from driv ing

Drilling is u ed to install pile A drilled pile is a cast in place pile con tructed by pouring con crete in a drilled haft This avoids vibration or displacement and heave of the ground Noi e from driving is reduced Holes can be drilled where re stricted headroom would prevent driving long pile A bell shaped cut at the bottom increa es bearing area and pile capacity Drilling equipment is light and easily portable or is truck mounted Precast piles are sometimes set in drilled or cored holes and grouted in place

Types of piles Wood piles cut from straight tree trunks are widely u ed Most commonly u ed in North America are southern pine Dougla fir oak and cypre Wood piles buried in the ground are subject to decay and insect attack unle s sub merged Wood piles above ground are al o subject to fire In marine loc itions piles are expo ed to decay abrasion and marine borer attack As a pre servative wood piles are often treated with creo sote or a creo ote coal tar mixture applied under pre sure Mechanical protection in the form of con crete jacketing pipe sleeves or metal heathing is al o sometimes used on marine piles Allowable load on wood pile are usually le s than tho e on concrete or steel piles and they will not stand as hard driving

Precast concrete piles are square octagonal or round They may be of uniform cro s ection or tapered full length or may have tapered points Pre tre ed concrete pile may be used Sectional hollow precast concrete piles are made of hollow spun reinforced concrete ections trung together on ten ioned steel cable running through longitu dinal hole

Cast in place concrete piles need no storage pace or special handling equ pment a oid the cut ting off or extending in ol ed in making length adjustment and cannot be damaged by dri ing Unca ed piles may be u ed where it is certain that neither soil nor water will fall to the hole or queeze into it and reduce the size One method i to drive a casing pipe and core then pull the core place concrete et the core on the con rete and pull the ca ing a concrete pede tal may be driven out if de ired Cased pile are i sed where upp t is required for the ide of the l ole and v here v a ter occur A temp rary hea y outer ca ing is driven and a permanent light l ell in ted In one method a core i dri en with the tempo ary ca ing to displace the soil in other method c ncrete o metal base are u ed to keep il o t of the ca i g Thin metal shells may be driven by internal man drel which are withdrawn and the hell filled it con rete

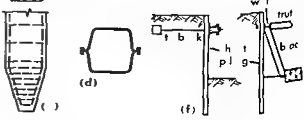
Pipe piles consist of teel pipe of 6–30 in in diameter Ends may be clo ed by hoe or open Open type piles are u ually cleared of oil by jet ting Both type are i ually filled w th c ncrete Pipe piles are capable of carrying large load to rock and lengths of 200 ft have been u ed The are u ed where rock is within reach for end bea ing where water conditions would require u e air if cais ons were sunk and where oil di plac ment must be avoided They are often u ed for u derpinning where they have been driven in ecti as short as 2 ft in re tricted headroom

Pile designs H piles are rolled teel ecti frequently u ed as pile They are uitable f penetrating rock or other hard material with les effort There is a wide range of izes and wei h Lengths have exceeded 200 ft Protection a a corro ion in upper portions may be required

Box piles are made by v elding to either t o tions of teel heet piling or combinations beam channel and plates They perform same functions as pipe piles They are u ually filled with concrete but can be cleaned out filled to any depth for trength and protection the interior again t corro ion

Composite piles are piles in which the upper lower portions consist of different types of pi This i done to secure the particular ad anta e a certain type without the expen e of u in throughout For example concrete upper ecti may be used on wood lower ection where latter would decay if they were near the urf H or pipe lower se tions may be u ed under concrete piles where it would be too expen i u e concrete alone

Sheet piling is a vertical wall compo ed of in locking units used to retain a difference in gro elevation in which the bottom support is obta by driving the toe below the lower level Sheet ing may be wood steel or concrete and may temporary or permanent Factors affectin ch include cost ease of installation availability vage corrosion decay ability to with tand dri lateral strength and ea e of making connecti Sheet piling is driven by pile hammer Ali m and i istance to thrusts are provided by horiz ntal walers and braces or tiebacks



Fg 3 Pl d g (a) P c t co c t p le (b) H pl ( ) P p p le (d) B p l l sh et pl g s ct (f) Sh t p l g w ll

on the starboard bow t n degrees abaft the port beam or two p nt the port q arter)

Aboard hip b aring a e usually mea ured (1) by noting when two objects are in rang (di r ctly in l n) (2) by m ans of a uitable attach me t to compa s or compass r peater (3) by p) m a ompa l ke ir me t without d re t e pr perte (4) ele t onic lly by rad o di ect on fi d r radar or by th nd cat on of the re e nd c tor f a ele t on sy t m of na ig t n S DIRECTION FINDING EQUIPMENT RADAR

D sta c Th i ow ge rally mea d by ra dar i na t cal mil or ya d (m t rs n co nt ies n g th m t y tem)

D ffe ent l d st nc Between tw p i t ch d ta c i u ally m ed le t oni ally by m an of the e ei d t f a hyperbol c nav gat y t m The r ad g i g u lly n m pe t it h s a m ond (ne millionth f a eco d) ne hund edth of a lan width See HYPER OLIC NAVIGATION SYSTEM

H ed pth D pth f wat r m a ure l in fe t fath ms (6 ft) M t pe i l ts a e us d by mari f om c t es Meas r ment may b m d by hand l ad (p on n ed l d) l ad e l t atta h d t a l und ng m h ne a r el f wi e t o e end f wh ch s att h d a w ght h h c rr es a dev c f re o d g d pth m c mm nly by e h o de a d i e wh h em t son ult son gn l i the wat d t m th et n of th h S ECHO SOUND R

A lt tud He ght f n raft i me s r d n f et (m t by na g t r f om c ntr es) by m a f a alt m te A b m ir c *h mete* d t m s he ght b e e le l o s me ther (level by me ing the atm ph i p e at th a raft A absol te alt met d te m es h ght bo e the t m ally by me ur ng th t m nt rv l bet e t an m n f a l d the r t n of t ech f om the surf ce o b m t m th pha m d ffer nce b tw th i m tt d gnal a d t e h S ALTI T TER P LRE AL I I TE R DIO

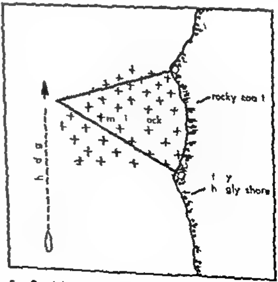
Position determination l m p l ting p i t n g lly d t rm n d by me n of l of po it m h nd t ng es f po bl p i l th aft at ll t m of me em nt A m l b r ng p d a t ght l ne f p t n (tu ll p rt of a g t le) pa ng thr ugh the bject ghted A m d d stan e m de a l l n f po it m th th nje t th nt d th d i m th r di s A me red d ff e t l d t n pro d a hyp rbol c l n f po t Whil tra ght o ula l ne of p ti n i ll pl it d d tly o the na t l h rt pe l h rt r t bl *g e ally* d t inte p t l yperbol l of po its D pth f w t r h ght l ft g lly d n t p i de a l n f po t n nl *th raft* es d i f atu u h a the 100-f th m rve nt n dg

A p it alled a fi s d t m ed by c s ng tw m l n f po t o taken m lta

o isly or nearly so If one li e is adjusted f r an appreciable time a running fix is obta ned This is omewhat le s rel able than a fix A two-bearing fix is shown in Fig 1 Figure 2 shows a fix obtained by means of a b aring and distance of a single obje t

In aircraft p loting is performed somewhat dif ferently When i ual landmarks are u ed they are gen rally ch cked off u e s vely from a li t or a onsutt l cha t a they are pa ed Radar and ad o m rk r bea ons are u ed in much the same manne Hyperb l and ther long di t nce sys t ms a e s d s i marine a gati n Mod rn ra di range and me land ng ai ls are ed l v k ep i g th n edle f spec al nd cat centered V i ual and aural s gn l are u ed in om older r ge Ai b ne radio d rect on f der are gen erally of the a t mat typ p ovidi g a continu us nd c ti n f d recti n of th *transm tter See* NAVI GATION SYSTEMS ELECTRONIC

Positi e ther ab ard h p or n tl air may be obtained i ther ways tl n by cr ng line of p s t on Cert in combinations of ucce ive bear ings of th ame bject pro ide immedi te indica ti n of p t o Simultan us h r z ntal angles b t n th ee object an be et on a three-arm p o t actor (alled a stati pointe by B it l naviga t r) and the p it n determ ned b fitting the arms of the tr ment to the hart ymbol r pre ti g tl bj t The h r z nt l angl s are u ally tak n by mar ne ext t Th s pr vides a ac u ate p ti met me u d n h drog ph c a m yi g r l l c t ng th poi t of l tt g g an an h r but eld m f r othe r p e A l e of sound g pl tt d n a t nsp rency at the orrect d ta ce t rv ls at the le of the ch rt a d then mat h d by t i l and r t the so ind gs hown o the h t *may p ov* de a el able indi t on of p t n wh re the bottom t p gr phy ha a *dis t n t p tt n Und* r fa o l le c nd ti n a bot t m p ofile obt ed by a r co d g l s nder an pro de a b tte p ti n



Fg 3 A ho t l d g gl

meeting production schedules On the other hand arrangements should be made to credit the operation with a fair value of the product manufactured so that the net amount remaining will represent development cost more accurately *See* PRODUCTION ENGINEERING [J E W]

Piloting

A form of navigation by which position is determined relative to external reference points usually fixed points on the earth It is the oldest form of navigation Primitive man learned to guide himself by means of prominent rocks trees bends in the river and other visible landmarks before he had any instruments other than his five senses Piloting usually called pilotage by aviators remained little changed until the application of electronics to navigation in relatively recent years Before that time piloting was associated with nearness to land or other dangers to navigation and frequent or continous determination of position or positional information

Position of a craft is determined in three ways Dead reckoning is the advancement of a previous position for subsequent motion of the craft Celestial navigation uses celestial bodies determination of position being with respect to the terrestrial points having the bodies momentarily overhead Piloting uses points generally fixed points on or near the surface of the earth for determination of position These traditional methods are now supplemented by electronic applications to navigation problems and by several other aids to all navigation

Piloting and celestial navigation are different despite some similarities In piloting position is determined relative to the points upon which certain measurements are made (sometimes indirectly) whereas in celestial navigation the objects observed merely provide certain information which is used to establish position relative to other points This distinction applies even in space navigation

Points or marks Natural landmarks the only piloting aids available to primitive man have been supplemented with a great many man made aids to navigation Such aids are of several types Beacons both lighted and unlighted and lighthouses are at fixed positions on land or in the water Buoys both lighted and unlighted and lightships float in the water being moored at desired points Unlighted aids are called daymarks These are given distinctive shapes or coloring to assist in identification A light installed as an aid to navigation is given a distinctive sequence and duration of light and dark periods and color or colors by which it can be identified These characteristics are shown on the charts and given in the light lists available to navigators

Some other marks are useful but most are visible aids to navigation Bottom topography can be of assistance in locating the position of a vessel Aircraft aids to navigation consist principally of electronic aids and lighted beacons Electronic aids

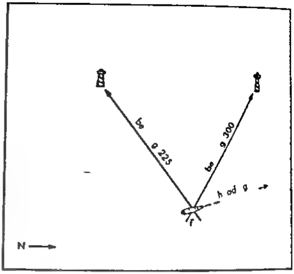


Fig 1 A fix from two bearings

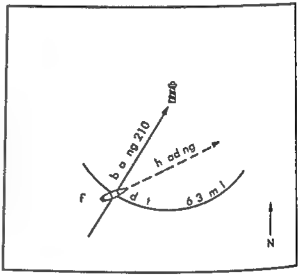
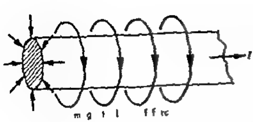


Fig 2 A fix from a bearing and distance of one object

consist chiefly of beacons of various kinds airway radio ranges and the various electronic systems of navigation discussed in other articles on navigation

Measurements The measurements made for piloting purposes are of direction distance difference tial distance between two points and distance to the bottom aboard ship or to the surface of the earth in aircraft In some electronic systems these measurements are made indirectly as by matching pulses on an electroscope counting dots and dashes or centering pointers

Direction Bearing is the principal designation of the direction of a landmark It is usually stated as angular distance from a reference direction usually true magnetic compass or gyro north Values are generally given in integral degrees (although half and quarter degrees may be used) using three figures from 000 at north clockwise through 360 Relative bearings use the heading of the craft as the reference direction and may be stated as above or right and left through 180 or with reference to some part craft (a broad



g 1 h p v e ry g d
Arr w t l ft how d cto f p h p s

: ts of th o d f 100 000 amp s were ndu ed t low ltag ı t h ız nt l r g h p d f ed ı t l lo d (e F 2) At th rr t the ch p e ure n be la ge tha th hydr tat c e u e ex rted by the f d metal nd a ımp f r l (g en ab ve) sho the p n h ı re ı a a the r d s l the c nd c r d c e C seq ently the p e e at a nar w k n th g f fu ed met l ı able t q t the fluid m taf unt l the neck p ch s ff ompl t ly cutt ng off th cur e t Th l d t very a even he t ng f th cha ge Th t m y ch effect gı e t th pro e by C. Her g n 1907 The tech ı al d ffi lty w e t ally e me by m k g the pl f the rı g vert c l d b m g ıt de ply b low th f ee s fac l the fu ed m t l The f c f th p nch eff ct h al be kn wn t m fe t t elf b a ru h n of t b l r c nd t vpo ed t l ge mpulsı e e t h c u l ght ı g st oke hı l p e h t ı ut

Thermonuclear applications Th t mp tu e qu ed f the p d tı n f a p fit l le il rr o l a e gy bala l om d ute n r the g n f 50 × 10⁶ K e e l h nd d × 10 K h t mper t ld be tt d nd *main* ed l f th he ted pl m w a fully ı l ted n all d f m th w ll f the ap p t by um whı h h th fu t n n t ly f p t g the pl sm f om l e ng l d by t u h ng the w ll b t l l e lud g fr m the pl ma any f gn m tt wh h wo ld *tably* be ev p ted fr m y k w mat al wl h wa e ı s l to such t mperatures Th utward pre s r f the pl ma mu t l l alanced ın me way without re t n on mate ı l w ll and thı has t b don by ome c mbination f electr c and mag et c fields *Se* FUSION NUCLEAR MAGNETOHYDRODYNAMICS PLA MA PHYSICS THERMO UCLEAR REACTION

The e are only a lim ted n mb r of w y ın wh ch mag et c f ld a be arranged ar d the *pla ma to hold ıt t ther nd f the e r that f th ch effect A fu ıon eact u ıng th s type* f c nfi ement wo ld ıde lly be a tor ıd l tube ın wh ch the c fined pla m w uld float the pla m ca ry ng a l rge el ctrı urre t ı d ced ın ıt by magnetı ınd t n f m a t a f rmer c r pa ı g th ugh the axıs of the tor . The f nd m ntal equ tıon fo the pınch effe t n a gas der ved theo-r tıc lly by W B tt ı 1934 gı th current *I* requı ed for the ınward p nch pre re to b la c the utwa d g p essure

$$I\ /200 = Nk(T\ \ + T\ )$$

wh re *I* s the t t l cur ent ı mperes *N* ıs th n mb r of ele t ns (also th n mber f ı n) per ce tımeter length of th pın h (ndep ndent of the *radıu*) $k = 1\ 4 \times 10$ *erg/* K (*B*o*ltzm* nn s n tant) and *T* and *T* a e the temperatu e n K of th ı n and le tron r spectı ly

Experımental studies I e al two typ s of ppa atu h e been u d n stud s of th p h *eff ct* (1) tra ght d ha g t bes c mp ed of quartz or por ela w th a metal lect de at e ch end nte d d f ho t d at n stud es whe e the co l ng f th pl sm by th r latı ly c ld le t des s lıght d r ng th t m of the e p e m nt d 2) to o d l d cha g t be al compo d f q art r p r el ı wh th pı ch s endle s a d c n eq tly m re ffect ly c nfi ed th n *ın th fi* t type of appa at and the c t ıs ı d ced ı to the d h ge by magn t o pl g t pr m ry wı d I both a es u nts of 50 000–500 000 amp re bta n d with g d nts of 10–100 v lt / m l ng th p n h The p ım p e u c ha ged nden w th *capac ty of 4–5 µf* cha g d t 10–100 k Th rre t ı th d s h rge s p dly rea h s p k

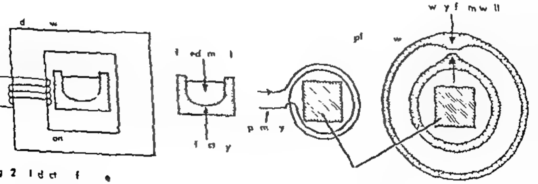


Fig 2 l d ct f e

A vessel can sometimes be kept in safe water without a fix. In an area where the bottom shoals gradually, a well chosen danger sounding can give warning in sufficient time to prevent grounding. A danger bearing of some object well ahead can provide an indication of a dangerous situation if the measured bearing exceeds the danger bearing. An off-lying rock or shoal can sometimes be successfully avoided by keeping the measured angle between two objects less (or more) than a preselected horizontal danger angle, as illustrated in Fig. 3. Similarly, a vertical danger angle can be established between the top and bottom of a single object.

No other form of navigation presents the variety of methods or taxes the ingenuity of the navigator as does piloting. In no other form is judgment based upon experience so valuable. *See* BUOY; CELESTIAL NAVIGATION; DEAD RECKONING; LIGHTHOUSE; NAVIGATION; POLAR NAVIGATION. [A.B.M.]

Bibliography: N. Bowditch, *American Practical Navigator*, U.S. Navy Hydrographic Office, H.O. 9, 1958; J. C. Hill II, T. F. Utegaard, and G. Riordan, *Dutton's Navigation and Piloting*, 1958; U.S. Navy Hydrographic Office, *Air Navigation*, H.O. 216, 1955.

Piltdown man

A fossil human being, actually the product of a skillful hoax perpetrated in the early 1900s by an unknown person. Various fragments of what were believed to be two skulls were recovered from about 1908 to 1915 by Charles Dawson, a lawyer, near Fletching, Sussex, England, assisted by Dr. A. S. Woodward and Father Teilhard de Chardin. These fragments suggested a being with a thick skull but a large brain, a high forehead, and an extremely apelike jaw of early Pleistocene date. Crude stone tools and fossils of several Pleistocene mammals were associated. Accepted by some anthropologists as an actual primitive man but assumed by others to be the accidental mixture of human and anthropoid remains, Piltdown man caused great difficulty in interpretation of human evolution until the hoax was detected and exposed in 1953 by Prof. Sir W. LeGros Clark and Drs. J. S. Weiner and K. Oakley. They established by chemical and other tests that the jaw was actually that of an orangutan, modern and not fossilized but stained to appear so, that the teeth had been filed to change their appearance, that the rest of the skull was chemically different from the jaw, and probably pathological, and that the fossil animals had been introduced from various other places.

The fossil was named *Eoanthropus dawsoni* by Woodward 1912 (also *Homo sapiens dawsoni* by Kleinschmidt). The jaw alone was named (by those originally assuming it to be an ape's) *Pan vetus* (Miller, 1915) and *Boreopithecus dawsoni* (Friedrichs, 1932). The remains are at the British Museum of Natural History. [W.W.H.]

Bibliography: J. S. Weiner, *The Piltdown Forgery*, 1955.

Pimento

A type of pepper (*Capsicum annuum*) grown for its thick, sweet, fleshed red fruit. A member of the plant order Tubiflorales, pimento is of American origin and gets its name from the Spanish word designating all sweet peppers. In the United States, however, the term pimento generally refers to the heart-shaped varieties grown in the South for canning and used for stuffing olives and flavoring food. Perfection is a popular variety. Harvesting begins when the fruits are fully red, usually 2½–3 months after planting. Georgia is the only important producing state. The total annual farm value in the United States is approximately $ 000,000. *See* PEPPER; TUBIFLORALES; VEGETABLE GROWING. [H.J.C.]

Pina

Pina, or pineapple fiber, is obtained from the large leaves of the pineapple plant grown in tropical countries. This natural fiber is white and especially soft and lustrous. In the Philippine Islands it is woven into pina cloth, which is soft, durable, and resistant to moisture. Pina is also used in making coarse grass cloth and for mats, bags, and clothing. *See* FIBER, NATURAL; PINEAPPLE. [M.D.P.]

Pinch effect

A name given to manifestations of the magnetic self-attraction of parallel electric currents having the same direction. Since 1952 the pinch effect in a gas discharge has become the subject of intensive study in laboratories throughout the world since it presents a possible way of achieving the magnetic confinement of a hot plasma (a highly ionized gas) necessary for the successful functioning of a thermonuclear or fusion reactor.

Ampere's law. The law of attraction which describes the interaction between parallel electric currents was discovered by André Marie Ampère in 1820 and can be stated as follows: the force of attraction in dynes per centimeter length between two thin straight wires r cm apart carrying currents of I_1 and I_2 amperes (amp), respectively, is $2I_1I_2/100r$ (*see* AMPERE'S LAW). The law applies equally to the attraction between the individual components of a current in a single wire. In which case, for a cylindrical wire of radius r cm carrying a total current of I amp, it shows up as an inward pressure at the surface of the wire (Fig. 1) given by $I^2/200\pi r^2$ dynes/cm.

For the electric currents of normal experience this force is small and passes unnoticed, but note that the pressure increases with I^2. At 100,000 amp the pressure amounts to about 1 atm on the surface of a wire of 1 cm radius, and at 10 amp the pressure is about 10 atm, which is considerably greater than the pressure produced by the detonation of trinitrotoluene (TNT).

Manifestations. The pinch effect first showed up practically in certain early types of induction electric furnaces in which … alternating

pletely t d ed m ng tor dal tab l z d p nch ma h ne thr ugh lat 1958 were pr duced by th Lo Alam Pe hap at on S 4 wh ch p d c s as man as 2 × 10 eut o per d s harge E en th pin h n t c mpletely tabl The temperatures bta ned w th thi appa atu a m a ured by mag net c pr be ar n th v n ty of 500 000 K wh ch s too l w fo the m n clear ff ts a d the pe ime t l indic t o that th p nch obta ned i still unst ble and l s g en rgy to th walls. Th lo pro e f n hecked w uld be qu t fatal to any a p r t on f r i g the tab l zed pi ch in a th rm nuclear eact a d th it c l problem is pres nt s t xpl by what p e s th n g) i esc p n Th r appear to be tw p ib l t s (1) Altho gh th s pi che would be table a c rd g t th riter a of 1952 they a e u tabl ac o d ng t th r te i de d in 1958 f r hyd magnetic stabil ty of p l with d ffu e b d e u h as the pi h h e and this du l n tab l ty ma b d h g th h t pla m int the w lls (2) V ol nt n llations of the le t on w th e pe t to the n (pla ma cil lat n) a i pr n ple b e t d u d r rta n ndit n f m the ne itable elst e d ft n ti n f the s and le t ns o i ted ih th lar e le t ic u rent i the pl m wl ch e n i turn shake the p tiel s ac th onfining magnet c field If the observ d i turn out to be due to th fir t p bil tv lone t can b u ed by th imp t n f a r r ed ax al m gn t c f ld e r al to th pin h l d o du t down th ax f the tube (ha d m p ch) a d the e h t truly tabl pi h m y l b tt th e b for Altern t ly if th nd m th d d ib th p oce s f e gy pe pr mi ng gg t n f r a c r h e b n m de a d the t bil ed p nch m y h e t b band ned [J L T]

Bbl g phy R K M La d h ff (d) *Th Pl m n M g n F ld* 1958 Un t d N t o *Th t c l a d E p m tal Asp t f C t ll d V l Fu* l 31 C t ll d F D c l 3 Pr ee nd Int n Conf Pe eful U At mic Ene gy 1958

Pine

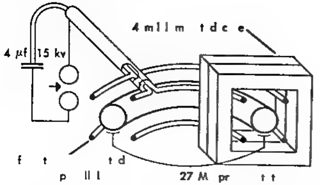
Th gen *P* f the p ne fam l b r ter z d by eve gr l v u lly t gl t cl ter (f s i les) f 2 5 l gl The e about 80 k own p es d tr b ted th gh ut the No th Hemi ph e B tan c lly the l s f tw k d (1) a lel k f rm the p m y leaf wh h ubte d a m h h rten d a d e e t ally d du us hoot b a i g (2) th sec da y le es n edl The w od f p ne e ly re gn ed by the num r u re in duct nd by the ch ra te t c od (e SECRETORY STRUCTURES PLA T) Th p n ma l d d d into tw cl es d g t the n mbe f l es a l te

Soft or white pines Ex ept f r the n t p n the h t p e h 5 dl i l t r Ea tern wh t p *P st b* rang g f m 90 t 150 ft in ight is f u d in th northea tern Un ted St t s

Fg l P e s ( ) P us (b) P t (c) P g a (B o kly B f G d B o kly NY)

west to the Lake t t dja e t C nada and the App la h a M ntain reg o Orig n lly it was the mo t imp tant t mbe tree f the eastern Un t d State and Ca ada w th t nd of app xi m t ly 750 000 000 000 boa d ft About 800 000 000 b a d ft ut an all and the t t l qua t ty f saw t mb n th *United St te* t p e nt i sti m ted a abo t 15 000 000 000 b a d ft I the am unt f ann l l mber c t e tern wh te pi e i n w ee ded by the thern hard p nes D ugl s fi oak p derosa pi ar d h ml ck (see DOUGLAS FIR H MLOCK OAK) The wood of a t e wh t p e i l able beca e it an be e l w k d s l ght a d s ft a e n t pl t when na l d p l h well d does not wa p o well app ably Alm t ev ryth ng f m h pm t to m t h cl d g u h item d ors fram ng fi i h box n l rates ha e b e made f om th s rviceable wood Howe er t i now rest i d t mo part ul r beca e of i creasing s a cty a d value

Of th weste n wh t p n the suga pine *P l mbe tia* is the m st mpo t t Th magn f nt P c fi Co t tr e att n ng a h ght of abo t 250 ft and ha ing large cones 10–20 in lo g It l mb d only O eg n and C l f rnia where it r ks i l me d alue with redwood (see



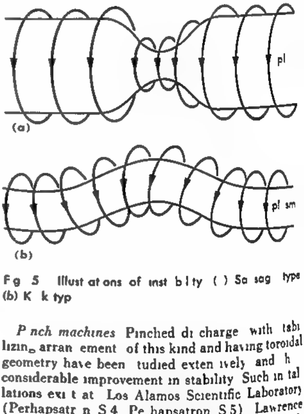
F g 3 Schemat c d ag am of Perhap atron

few micro econds and decays to zero in a damped oscillation (ee Fig 3)

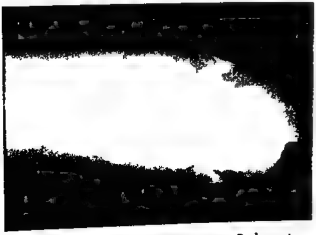
Instability Characteristically as can be seen by high speed photography the di charge forms at the inner urface of the discharge tube wall and con tracts inwardly forming an inten e line on the axis (Fig 4) the ingoing wave usually bounce slightly the contracted dischar_e rapidly develops necks and kinks and in a few microseconds all structure is lost in an apparently turbulent glowing gas Thus the pinch turns out to be unstable and the plasma confinement is soon lo t by contact with the wall The cau e of the instability is ea ily seen qualitati ely the pinch confinement can ell be described as being caused by the ma_netic lines which encircle the pinch and resemble slippery rubber bands which are stretched longitudinally but trans ersely are in compression (see Fi_ 5) For a uniform cylindrical pinch the magnetic pinch pressure is everywhere equal to the outward pla ma pressure but at a neck or on tl e inward side of a kink the magnetic lines crowd together creating a hi_her pre sure than the outward gas pressu e Consequently the neck contracts d wn further and the kink cuts in on the conca e ide and bulges out n the convex side

Neutrons are reported from these linear pincl machines ometimes in great numbers (nea ly 10 per pulse from the high power Los Alamos linear pinch machine known as Columbus II) It turns out that these neutrons are emitted preferentially in the direction in which a deuteron would be accelerated by the applied electric field and are associated in ome way with the in tabilities that have been mentioned They are not produced by a thermonuclear (fusion) reaction occurring through out the pinch

The instability has a di astrous effect on the achievement of thermonuclear temperatures by the pinch effect and great effort has been devoted to overcoming it An improvement i obtained by adding an axial magnetic field down the in ide of the pinched discharge This has the effect in prin ciple of stiffening the discharge again t the hort wavelength sausage and kink deformations Next a highly conducting wall parallel to the di charge prevents the escape of magnetic line trapped be tween the pinch and the all thus providing a cushion which should resist long wavelen th drifts into the wall



F g 5 Illust at ons of inst b l ty ( ) Sa sag type (b) K k typ



F g 4 Xe o p ch d d h rg Pe h ps t o to us

P nch machines Pinched di charge with tabi lizin_ arran ement of this kind and having toroidal geometry have been tudied exten ively and h considerable improvement in stability Such in tal lations exi t at Los Alamos Scientific Laboratory (Perhapsatr n S 4 Pe hapsatron S 5) Lawrence Radiat on Laboratory (Toroidal Stabilized Pinch Machine) in the United State At mic Energy Es tabli hment Harwell (Zeta) and As ociated Elec tric l Industrie Aldermaston (Sceptre) in the Unit d Kingdom and were reported from other nation n tal ly the S iet Union Sweden France and Germany at the Gene a Atoms for Peace Con ference in 1958 The most ambitiou of the e device is undoubtedly the Zeta machine (torus b re ~ 1 m) from which the neutrons p oduced ($\sim 10^6$ per di charge) were su pected in early 1958 by U ited Kingdom experimenter to be therm nu clear but ult mately we e fo ind to be the re ult of accelerated deuterons like th e fr m the linear machine

Possibl e asons fo energy loss The mo t p wer ful ne tr n b r ts as well one most

t Manufa tur r f e tal il us p e oil s a sou c f p m terp e l a d also f som f t the e nt t e t Ab ut 28 000 000 g l of pine l p du ed a nu ll n th United State

A n mbe f e enti l o l d d f m th needles a d e f r s tl r pe e f p nes Mo t of the s r p du d in Sw tz rla d A s t G rm ny a d Ru S e ESSENTIAL OILS

[F L S]

Pineal body

In t m t c mplete f rm th p al may be re ga d d as n i t of a e f g n t ons or tgr wth fr m th th d entricle t th oof of th d n eph l n f th b The p n l app ra t n t t tes n f the old t p rt f the br in a d wid p d th gh ut the tebrate a mal ki gd m Th two p ipal c mp ts of thi app at s a ally k w a th pa tal ye r p l ey nd th p n al g n o th r phy i S e BRAIN

Parietal eye I ma y pec es pa t ul rly mo g m f th ld bl od d a imal the p s t l ye mpo nt pr ent d i a p t n to b fl ne d by ol r rad t o I ome pe s t f rm a cl it ted ben ath a lay r of tr n l t k n t th it l e w th n r be ath a l ht tr n mitt g n of fo ame n the skull The pa t t l ey mp n t m y r a t ha a d ect n rve ecti n th the b a n When a n e t e id t t n ects w th e g n f th bra k ow the h b l r pp s t hi f t n kn wn t be c nn cted t h t t es th hyp thalam s nd m di n t the tern l e p l n m pec of a m l

Structure Th lo g r epiph i that mpo t of the p eal pp t wl ch ppe t b gl d la n m t rt b t s i lud ng m n lt h b h w t b t ry i som of tl rtel i

Th p n l pp r t i t ell h bly la so th t t t uld a il te th bl od t m

Function E p m t h fly f h d mph b nd te th t tl n fl n n m la i p gm t d p t p n t l ght St d n pt l g est l i tabol m nd p d t d p r m t l d and m n m mmal also nd t m ff t tl ep od i t t m Cl l t de m n l gges th t som ph l g l l u n h p h t een th r l a d th ep odu t i m e

Th t m t oc t w th mpo ta t e l p th a tl b d t l pply nd th t l g l l ll a th re t tud w th l r t t pe ggest h gh l l f ph l g t t f th pi l g r ep phy St l tl f t l ght pt tl p t l mpo t ld l lood l t t t ggest s m l w th r pect t sol r

[H I]

Pineapple

A low g ow n pe en i l plant ind ge n to Ame a The cult t d ari t e belo g to the p cies *Ana as ati us* of the pl nt o der Fari nal The ed ble p rti n f th p neapple devel ps from a ma s of a te o a fl hy flower t ck hav i g pe tent br cts On the c ltivated type th flow r r ually abo t e The l a are lo g d sw rdlike u ally r u h ed ed a d g ow to a he ht f 2-4 ft C mme cial pla t ngs bea fr it t the a e of 1 20 months a d may c ntinue to be pr du t ve f r s mu h as 8-10 ye r Pr paga tion i by ucke s ll t wh ch may be r t d n and l t are u ually t d rectly in the field whe they r t produ e Th l afy c w ma be sed a cutti but b a e they are h t d w th the *fru t, othe m th d f propa* g t n a e m e at fact ry

The pine pple warm cl m te plant i nj red by t mperatu e below 32 F It does be t in a d y tm phe e and el t ly poor o l but r p nd ell to fe t l e Th m j p oduc ng area the H wa i n I land whe p c al method f cult re nd h ve t n ha bee de lop d A p per *mul h* ed in th p du ti n f much of the H w an p apple crop Th pape la d in long t p by a p tal ma h wh h pull o l e the edge f the t ps to hold them pl c The mul h a d in weed nt ol nd de rea m i tur p at n f om th il B au e of th tend ncy to r chl ro of pl nt gr wi o thes ls p a ng w th r n alt i f eq ntly a p rt of

P ppl A t how g f t d l (USDA)

REDWOOD) The annual cut is 300 000 000–400 000 000 board ft The pre ent stand is estimated at about 20 000 000 000 board ft with approximately four fifths in California Other white pines in the We t are western white pine *P monticola* a mountain pecie found almo t entirely in Idaho Montana and Oregon limber pine *P flexilis* one of the smaller white pines of the Rockies and white bark pine *P albicaulis* also a mountain spe cies with a more northern range

The nut pines or pinons are a subgroup of the Southwe t with fe er needles sometime only one

Hard or pitch pines Red pine *P resinosa* also known a Norway pine reaches a height of 80 ft or more and is native in the northea tern United State fr m Maine to Minne ota and adjacent Can ada and outh along the mountains to West Vir ginia The needles are in pairs and the bark has a red brown color hence the name The wood is fairly oft but a little harder than that of eastern white pine The more dense red pine is al o stronger and is important c mmercially for general con truc tion sash door and window frame manufacturing flooring boxes crate and shipmasts but it is not durable in contact with the oil Frequently it is old in mixture with eastern white pine The tand in the United States has been estimated at about 3 000 000 000 board ft with about two thirds of the stand in the Northea t and the remainder in the Lake tates The average annual cut is about 150 000 000 board ft Technologically the red pine forms a sort of bridge between the soft white pine and the hard pine

The hard yellow pines have two or three needle in a clu ter The longleaf pine *P palust is* lob lolly *P taeda* hortleaf *P echinata* and the slash pine *P elliottii* are the principal trees of the outhea tern United States that yield the o called outhern yellow pine lumber a hard resinous wood in which the dark band of mmer wood con pi u ou ly alternate with the lighter colored pring wood *See* WOOD (ANATOMY AND IDENTIFICATION) The longleaf pine is the most important of the e being a leading world producer of naval tore The hard trong wood is used in con truction flooring railway car construction and hipbuild ing The longleaf and sla h pines are the most im portant trees for the production of turpentine a di tillate obtained from the re n when the trees are tapped The alue of gum and ro in ranges from $30 000 000 to $40 000 000 annually *S e* GUM NA VAL STORES ROSIN TURPENTINE

In the West the hard pines are repre ented chiefly by the p ndero a pine *P ponderosa* which attain a height of 150 225 ft and i found in the Rocky Mountain and Pacific Coa t region includ ing adjacent Canada The t tal tand and lumber cut from thi pine (including Jeffrey pine *P j ffreyi* which i c mmonly ld al ng with it) are exceeded only by D ugla fir and the utl ern yel low pin The t tal tand of w t mber i l ut 185 000 000 000 board ft and the annual cut be tween 3 000 000 000 and 4 000 000 000 b ard ft

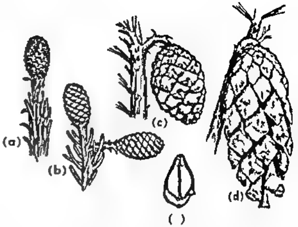


Fig 2 Scotch p ne *P nus syl est* (a) F male (a late) cone u fe t lized (b) Fe t l zed co es. ( ) St ge in developme t of c e (d) Cone open ng to d ch rg s eds (e) Seed scale show g two w ged s ed (A H Gra m *Illustrat d G de to Tre a d Shr bs* Har p r 1956)

nearly half of which comes from Ore on and ab t one quarter from California

The Au trian pine *P nigra* which ha two nee dles and closely re embles the red pine has darker bark and is much planted in North America a i the Scotch pine *P sylvestris* with two h rter bluı h needle (Fig 2) The latter doe o well un der American conditions that it has often bec me naturalized Other exotic pecies often cultı ated are mountain pine *P mugo* Japane e black pine *P thunbergi* and Swi s tone pine *P cembra* the last a 5 needled species *See* FORE T AND FORE TRY TREE [A H G]

Pine oil

A material fractionated from oil reco ered fr m long leaf pine wood *See* WOOD CHEMICALS Pine wood is either destructively di tilled or olvent e tracted t yield turpentine ro in charcoal and other u eful commercial product The recovered oils are further refined and pine oil re ult from a definite cut in the fractionation

Good grades of pine oil con ist largely of terpin eol A typical p ne oil contains

	%
α Terpine l	65 0
D hy dro α terpine l an l otl er tertiary alcol l	10
B rne l nd fe hyl alcohol	10-15
Estra le	5
Ketones	5 10

The textile i dustry u es pine oil a a penetrant disper ing agent wetting agent and inhibit r of bacterial growth in practically all wet proce ing of cotton ilk rayon and wo len g d In the paper indu try it is u ed a a wetting and le eln agent in coat ng and a a pre er ati e f ca in It find exten i e u e f r the preparation f l l grade di infectants liniment odorant ll k l i cattle pray and ther in ticidal prepara

ti n M nufa tu f es ent l ils pi e l sou c f pr m te pineol and also f some f t th r t tu nt Al t 28 000 000 gal f p ne l i p duc d ann ally n th U t d St te

A n mb r of es nt al l a e der ved fr m th needles a d nes f r u ther p es f pines M t f thes re p odu ed n Switze land Aus t a Germ y d R i S Es ENTIAL OILS

[E.L.S.]

Pineal body

I m t mplete f rm th p n l may be r garded a t g f a seri of evag nat n or utgr wths f m the th rd ent i le m th ool l th d eph lo f the l rain Th pi al appa a t tit tes e of the t part f th bra n a d widesp d th ugh t th rtebr t n mal k gdom. Th tw pt p l mpon nts of th app rat are u lly k wn a th pari t l y r p n l ey a d the p al rg r th p phy S Br i

Parietal eye In m y pec es tic l rl m g m y f the ld blood d m l the p t t l eye mp t p sent a d n posi n to be fl e ed by l ad t n In som pec es f rm es le t at d be th layer f t a l ent k n th r t l es w th n r ben ath a l ht t a m it g re on of f r m n the skull Th p r tal ye c mp t may or ma t ha d rect n rv n ct n w th th b a When a ne t ev de t t nect with r f th bra n kn w th l be l ppa tu wh h turn k wn t be nnected t h t tu th h thalamu a d m dl r

ll a to th nt f p le m pec f a m l

Structure Th p l g n p ph that mpo t of the p l pp tu wh h pp t be gl d l t m t rteb ates t l d g m n It ha b h wn t b t ry t m f th l w st t tes

Th p n l ppa t s n t ll h ghl a ula so that t e et n ld e ly e t th l lood tr m.

Function Exper m nts b efly f h d mph l a d ate th t the n fl en m l p gm t d r l nd r p t l ght St d ept les g t a l n m t b l m a d p d t a d per m t n h d d ma y m mm l l nd te m effect n the r p od t y t m Ch l t d t m n lso g est th t som phy l g al r l t n h p be twe n th p l a d th r p od t y t m

Th t m t oc t n with imp rt t n n al thway th hu da ul r pply nd th cyt l g l ev d w ll th t t d w th d t sot pes g est a h gh lev l f ph l g a t ty f th p l rg n p phy St d es w th ga d t l ght pt th p rt l y mpo ent ld blooded rt b tes d t n ry t l with p t t l a

[H.J.L.]

Pineapple

A l w gr wing peren ial plant nd g n t Am ri a Th culti ated t es bel ng t th pe ies *An s* tt us of th plant rd r Fari nales Th ed l le port n of th pi eappl devel p f m a ma s f ar es n a fl l fl w r tork l a t g pet t t l ra t On th c lt ated t pes th fl we ar ally abort v Th l a e r l n nd w rdlik u lly r ugh edged and gr w t a h ht f 2 4 ft Comm r i l plant g bear f u t at th ag of l 20 m nth nd may c nti e t be prod ti f r a mu h a 8 10 y r Pr pag ti i l v t ker r fl t wh h m be rooted n nd l t a u lly set directl in th f ld wh r th y r t p odu Th l aly r wn m y also l u ed c tting l t l era th y ar harvested w th th f u t other meth d f pr pa gati ar m re ati f t ry

Th p appl a wa m l mat pla t t inj red by t mpe at res bel w 3 F It d es best in a dry tmosph r and r l t ly poor l l t resp nd well t f rt l z r Th m j r p od t g r a t tl Ha n l la d wh r pec al m thod f ult r d harvesting h been dev l ped A paper mul h u ed n th p od cti f m h f th Ha wa p ppl rop Th pap l la d l ng tr p ly pec l ma h n wh h p ll w l s r th edg f th t p to hold them n pla Th m l h id weed o tr l n l decr es m tu e evapor ti n f m th so l Beca se f th tendency to chl r f pla t gr wing n thes soil p ays g w th n n l t s f q ntly a part f

P ppl A how g fru t nd l av s. (USDA)

REDWOOD) The annual cut is 300 000 000–400 000 000 board ft The pre ent stand is estimated at about 20 000 000 000 board ft with approximately four fifths in California Other white pine in the West are western white pine *P monticola* a mountain specie found almost entirely in Idaho Montana and Oregon limber pine *P flexilis* one of the smaller white pines of the Rockies and white bark pine *P albicaulis* also a mountain species with a more northern range

The nut pines or pinons are a subgroup of the Southwest with fewer needles sometimes only one

Hard or pitch pines Red pine *P resinosa* also known as Norway pine reaches a height of 80 ft or more and is native in the northeastern United States from Maine to Minne ota and adjacent Canada and south along the mountains to West Virginia The needles are in pairs and the bark has a red brown color hence the name The wood is fairly oft but a little harder than that of eastern white pine The more den e red pine is also tronger and is important commercially for general construction ash door and window frame manufacturing flooring boxe crate and shipmasts but it is not durable in contact with the soil Frequently it is sold in mixture with eastern white pine The stand in the United States has been estimated at about 3 000 000 000 board ft with about t o thirds of the tand in the Northea t and the remainder in the Lake states The average annual cut is about 150 000 000 board ft Technologically the red pine forms a sort of bridge between the soft white pines and the hard pine

The hard yellow pine ha e two or three needles in a clu ter The longleaf pine *P palustris* lob lolly *P taeda* hortleaf *P ech nata* and the slash pine *P elliottii* are the principal trees of the utheastern United States that yield the o called southern yellow pine lumber a hard resinous wo d in which the dark ba ds of mmer wood con picu ou ly alternate ith the lighter colored spri g wood *See* WOOD (ANATOMY AND IDENTIFICATION) The longleaf pine i the most important of the e being a leading world produce of naval t re The hard strong wood is used in con truction flooring railway car construction and hipbuilding The longleaf and la h pines are the most important trees f r the producti n of turpentine a distillate obtained from the resin when the trees are tapped The value of gum and ro in range fr m $30 000 000 to $40 000 000 annually *See* GUM NAVAL STORES RO IN TURPENTINE

In the We t the hard pines are repre ented chiefly by the p ndero a pi e *P ponderosa* which attains a height of 150–225 ft and i fou d in the Rocky Mountain and Pacific Coa t regions including adjacent Canada The total stand and lumber cut from th s pine (including Jeffrey pi e *P jeffreyi* which is commonly old along with it) a e exceeded only by Douglas fir and the outhern yellow pine The total tand of aw timl er i ab t 185 000 000 000 board ft and the annual cut be tween 3 000 000 000 and 4 000 000 000 board ft

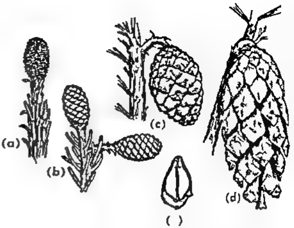


Fig 2 Scotch p e *P us syl e t s* ( ) Fem le (ovulat) one u fe t l ed (b) Fe t l zed cone ( ) St ge n de l pme t of c e (d) Cone open g t d ch rg seed (e) S d ale show g two w ged seeds. (A H G aves *Ill strated G de to T nd Sh b H p* 1956)

nearly half of which comes fr m Oregon and about one quarter from California

The Austrian pine *P ni ra* which ha t o needles and clo ely re embles the red pine ha darker bark and is much planted in North America a i the Scotch pine *P sylvestris* with two horter blui h needle (Fig 2) The latter doe o well under American conditions that it has often become naturali ed Other exotic pecies often cult ated are mountain pine *P mugo* Japane e black pine *P thunbe gi* and Swi s stone pine *P cembra* the last a 5 needled species *See* FOR T AND FORE TRY TREE [A H G]

Pine oil

A material f actionated from oil reco ered fr m long leaf pine wood *See* WOOD CHEMICALS Pine wood s e ther destructi ely di tilled or ol ent extracted t yield turpentine ro in charcoal and other u eful ommercial p oducts The recovered oils are fu ther refined and pine oil re ults from a definite c t in the fractionati n

Good g ades of pine o l con i t lar ely of terpineol A typ cal p ne il ntains

	%
α Te pi eol	65 0
Dil y l o α t p e l a l tl er terti ry lcohols	10
Borneol l f n l vl lcol l	10–15
Est a le	5
Ketones	5 10

Tl e textile indi try u es pine oil as a penetrant di per ing agent wett ng ge t and inhil it r f b terial g owth in pra ti ally ll wet pr ce ing of cotton lk ayon and w le g l In the paper indu try it i ed a w tting and le el ng ag nt i ati g and a a i r r at e f ca ein It find exten i e t f th pr j rat on f l i l g de d i fectant l nim nt cd m t l l k l aj ttle j ray a d tl m t i l l i r j ara

nm i ng The p te r thied f the body of the m le s e rı d nt a t ght piral ı c tra t to the t ght l ng p ı ted ta l f th f m le

He y infe tat n by this w m a e c mm n It l m th upp r p rti n f the la ge intest ne The gr d female de ce d c the re t m and pa ut w th the fe e or they m y rawl o t of th tum at n gl t t dep t th r gg over the pe n l a e

The l f cy l e mpl t w thin an ı dı idual The f ct n bu ld up by the tran m n f gg by th fing r fi g rna ls and bed l thı g to th m th Ea h g neratı n la t nly 3-4 weeks a d th ınf ct n w ll d t ıf reinfestatı n by tle ı ge to f g sı prev nted

Sl ght nfect ns m px s un t c d b th a s r ı f t n w ll a ten e pr ıt s and nt tı al d tu ban es Anem a bed w tt g nd u ual re tl s ı the sleep al ng with an l tchı g are lly ınd e t o f th p e enc f pı worm a nd t n call d nte b A numb r of hem l kill p nw rm but g d p e a t aga n t festat n r t b taken

N pı k ng by h ldren m times result ın ı fecti n f the p al m a The w rm are al f qne tly f nd the rm l rm pp d x a d m y be the se f a b ta t l p rcentage of th a es f append ıt P nw rm cu th ough t N rth Am ltho gh th y re m r p eva l t w rm s S A RIDID A CARIS

[J D B]

Pinworm infection

An ı fe t o l kn wn a nte h a t the h m nte t l t a t by th p nw rm *Ente ob us m ular* The female m t d ı ½ n l ng th male m ch m ll B th h b t the larg ı t e b t th m y al be ded Th f m l p d e l tho a d gg wh ch a e mul t n t t P g nt w rm tw to f r w k ld xp ll d n the feces r wl out f th n t l y th dde Th m m nt a se t h ng a d erv d rd m y en ue

Sc t h ng t m t l th g and ha d th n t t m y thu k me ut fe ted a d ı dd t scatt gg n th h u e Th s th n d n ı high h ld n t t t n nt mpe ate l m ı R tr ı f t may oc u by the l twa s t e k ı f th gg nd e t ring a the sı d l p

The d d agn ed by b rwing th w rm po tru n f m th n a d by mı r c pı al det ı f ggs n l swab It tr t d by ral dm t ı n of piper n o d th z f l week Fo ta n my PAR SITOLO Y MED CAL STRO GLYOIDEA

[J F S A]

Pipe flow

Co eya e of flu d ın cl de d t P pes ha been d f th nd f y a h t th d ta led und rst d ng f elo ty d trib tı n a d f en ly lo s ha m bo t du ı g th twent th

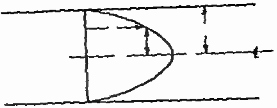


Fig 1 Lam v locity d t butıo

ntury S t fa tory eq ıatı n f r p edı ting the l n ın flow f wat r ha e be n ın e ın e abcut the m ddle f the n teentl n ntu y

Laminar flow The fl ıd m v p rall l to the p pe ax s ın a traight r u d p pe wh n the Rey n ld mber VD/ν t les than 2000 ın whı h V ı the a erag elocity D the p pe diameter nd ı the k nemat c v osity (s REY OLDS NU BER) The locity dı trib tion ı lam r flow ı para bol c (F g 1) a d the e ıuat n for elocity ı ı

$$= \frac{\Delta p}{4\mu L}(\ ^2 - r^2)$$

ı wh h Δp s the pre r drop ın l ngth L μ ı the b l t ı ıty nd r l r ar a l wn ın Fig 1 Discharg Q ın lam na flow ı

$$Q = \frac{\Delta p \pi D^4}{128\mu L}$$

nd ınd pe d nt f th ro ghnes f th ınt ıor p pe wall rfa

In lami ar flow tl flu d particles m ın str ıght l nes par ll l to th pipe ax ın tel p s g layers w th e h nn r layer m ıng m r rap dly than ıt adj t ut r l y Ene gy l se a y s the fi t pow r f the velocity so that by d ubl ng th d harg (r a e ag v loc ty) the p e ed p ı d lled

Turbulent flow In a pipe when the R yn ld number ı g e te than 2000-4000 normally the fl d part le no l g r mo all l t the p pe a The a t tran n v locity depend th natu f th p pı y t m F r h gh R y olds n mbers th d l mot n f lam n fl w be ome n tabl wıt fl d part les mo g ın ra d m p th with l g ır e e elocity mpo ts E gy ı dı sipated ın th turbul nt m t on with the l ary ng the locity t the l 7 0 pow Th Da cy W bach quatı for head lo h_f d e to tu bul t flow ı a pipe s

$$h_f = f\frac{L}{D}\frac{V^2}{2g}$$

n wh ch V the a erage l ty L ıs the l gth D the d m ter d f d men nless f tor d p nde t up n the wall r gh ess th fluid proper t es a d up n th l c ty and p pe d ameter $f = f(V, D\ \rho\ \mu,\ )$ with ρ th flu d den ıty and ϵ a the su of the ab lut ro gh f the p p wall ha ı g the dim n of le gth

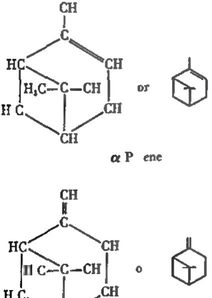
the fertilization program Careful control of the nitrogen supply in relation to the hours of sunshine together with the use of hormone sprays under certain conditions has made possible considerable control over the time of ripening an important consideration in obtaining maximum year round use of processing facilities Pineapples are also grown in the West Indies and to a limited extent in southern Florida In the latter area the average value of the crop for the period 1946–1955 was $83 000

Pineapples are consumed fresh in considerable quantity but because of distance from markets and the problems of transporting fresh fruit most of the crop is canned either as sliced pineapple or as juice In Hawaii the average yearly value of processed pineapple for 1946–1955 was $91 000 000 *See* FARINALES FRUIT GROWING (SMALL)

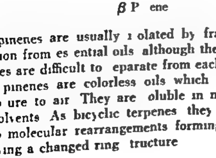
[J H CE]

Pinene

One of the most important of the terpene hydrocarbons α Pinene is widely distributed in nature and is the chief constituent of oil of turpentine The beta variety often accompanies the alpha and is usually present in small quantities Both exist as the dextro levo and racemic forms of optical isomers Although theoretically α pinene should be capable (starred carbons) of having two dextro and two levorotatory varieties no evidence of such isomerides has been demonstrated



α P ene



β P ene

The pinenes are usually isolated by fractional distillation from essential oils although the α and β pinenes are difficult to separate from each other

Both pinenes are colorless oils which resinify on exposure to air They are soluble in most organic solvents As bicyclic terpenes they readily undergo molecular rearrangements forming products having a changed ring structure

Physical properties

	α Pinene d l	d dl	β Pinene d l
Boiling point 760 mm	156 C		164 166°C
Density (0 C)	0 8 8–0 860		0 8
Refractive index 0 /D	1 466		1 46–1 48
Specific rotation	$d = +51$ $l = -51$		l –

α Pinene is the starting point in the commercial production of borneol camphor terpineol and terpin hydrate *See* TERPENE TURPENTINE

[ELS]

Pink eye

An acute contagious conjunctivitis caused by the bacterium *Haemophilus aegyptius* (Koch Weeks bacillus) This organism closely resembles *H influenzae* but is unencapsulated and serologically different Pink eye may occur in epidemic particularly among children in warm climates Diagnosis is based upon the characteristic diffuse inflammation of the conjunctivae and sclera and upon the isolation of *H aegyptius* on a blood containing culture medium such as chocolate agar It is treated with neomycin locally or broad spectrum antibiotics orally Recovery produces little immunity *See* HEMOPHILIC BACTERIA

[W F V]

Pinta

A disease similar to syphilis caused by a spirochete which occurs principally in certain rural tropical areas of Central and South America cases have been described from other tropical region The early lesions and the general evolution of pinta are similar to but generally milder than those of syphilis and yaws Generalized lesions develop a red dish purplish hue which is followed by atrophy and spotty achromia of the skin Treponeme morphologically similar to *Treponema pallidum* are present in small numbers in the skin lesion The infection has not been established in laboratory animal but has been transmitted to human volunteer Serious late complications have not been described The serological pattern and response to treatment are similar to syphilis Transmission is presumably by direct contact *See* SPIROCHETE SYPHILIS YAWS

[T B T]

Pinworm

A species *Enterobius vermicularis* of the class Nematoda phylum Aschelminthes also called seatworms This worm is one of the most common and annoying parasites of man Some estimates of the degree of infestation in the United States have run as high as 35% of the total population It is especially prevalent in children In some communities the incidence of infection approaches 100%

The anatomy of the pinworm is basically similar to that of *Ascaris* It is a small white worm the males being only 2 5 mm long the females 9 12

bly go d r ult m Pr ndtl e eventh powe l w

$$= \max\left(\frac{y}{\delta}\right)^{1/7}$$

wh h y the d ta ce fr m tl e p pe w ll nd th p p ad [V L S]

Bibl phy C. F C l l k T bule t flow p pe w th part ular r f r n to the t an i t n go b tween the m th a d r ugh p p l *J I t C I E g s (L d n)* 12 133–156 1939 V L. St e t *Fl d M h c* 2d d 19 8

Pipeline

Maj r s f p pel f r th t n p rt t n f pet l um wate (t) d: g ewag) hemi al (d t ff p l d coal nd ga uch a at al g te m a d mp e d P pel ne m t be l kp f nd mu t p rm t th appl at f h t p e are q d t f r e e n eyed ub ta th o h the l n Pip made of a va i ty f m t al and t d amet r f m l a t f h p t 0ft P : palm l t l teel wr ght a d ast iro e rete el y p od cts l m n m copp r t c me t a d a b t (e ll d c ment b t) pl t d w od

P r e s d bed a p es ure a d n p e u p p f m y p ur l b l l a d g l p mp for e ub tan th gh the p pe l t eq d l t P e e may l des l ped l by gr t h d s f x ple ty w t r m s f d f m ele t d t k r sy

\ p pip ed f gra ty fl w wher th g d t m al nd w th ut m j irr g l t s a w l l ert nd rta typ f g t n d t b t n v t m

Des gn f pipel d r h f t r a e q d p ty t rn l a d t al p u e w t a tight pa s n ch r t t s f the p p m t l h m al et t f th l q d er g b n ed nd or n

Mo t p p t j nt d alth gh me t p p m ol th lly t pl Th le gth f th nd d l t ns f p p nd th m thod f j n g th d p nd p n th p p m t al d am te ght nd q m nt f St l p p ect ally j d by weld upl g

et g Ca t n p p m y b j d by u pl ng th f b ll nd p g t p p by fill g th p b tw en th b ll nd th p g t th lked m lt d m t l l l d Fl bl typ j t w th ubb ga k t r l u ed f r j t g t n p p Th r bb g k t t d g a d d n ly th sol lem t maki g th jo t w te t ght

Ceme t m ta fill d l ad fill d r g d t p b ll d p g t j t t lly ed fo j n ng et t fied l y w r p p T ngue d g e g d ty m rt fill d j ts often d f n t p p l w p u t ll t s Th b h type j nt m t f eq tly d fo h b t s m t p p d t p p d high r es S PI E FLOW [L N M]

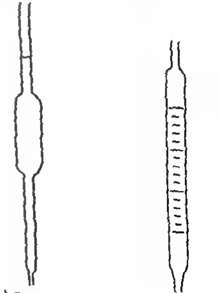
Piperales

A primit order f tl plant hel Di tyle d neae on l di g 3 famil es the l zar l t il family (Sa ura eae) the pepper family (P pera e) a d the Chl antl ce e Th e plant ha m ml nak d fl w r m the la t fam ly a mall l ra i lik p ria th Like th Sat r a a tl e Chl ran tl a e a ry mall f mily of n ee omt al

Tl pepp r f mily includes 12 g n ra a l 1400 pe e nd g n t tr pi al eg m l tl tl Old and th N w Wo ld Se ral p es ha e e n ide al l m e import e Tl f ut f P per n g um f Malaya a e dri d an l g nd t pr d ie mmer ial l lack p p p r r tl ed ly i gr u d t mak wh te p pp r The l ed berr f *P p* *ub l* f tl e Fa t Indies ar th e l el ed i med Tl Fa t Ind an nati es el w b t l n t c mb ned w th the f esh le es f *Pipe b tl* the b tel pepp r See BETEL NUT CUBEB PEPPER s ls DICOTYLEDONEAE E IBRYOPHYTA PLANT KINGDOM [P D]

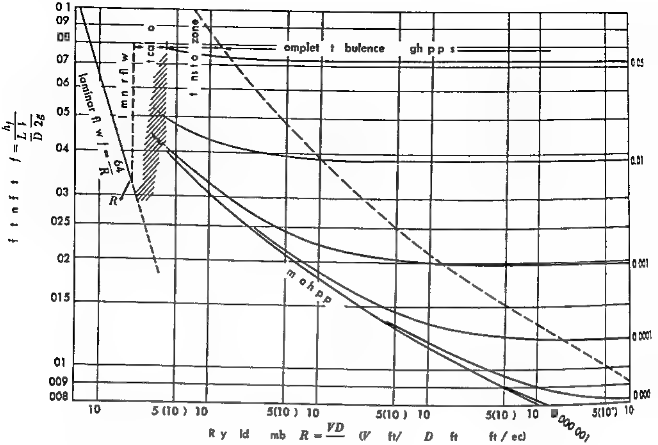
Pipet

Pip t t ally mad f gl s a d a e i ed al m t lt ly to d li er a rately kn w l ume f l q d l t n Th re a tw g n ral ateg es f p p t vol m tr r tra fer p pet and th g d at d m a t e t s typ (illu tra t n) V lumet ic pipet a e ed tl f ll wi g w y th liq d ked up al v tl e m rk n the tem abo the l ulb a d th upper nd i q kly lo ed w th the nd x fing a y adh ring l q d ped fr m the ut de f th l w r t m th level of l q d n th t m ll wed to fall l ly by gul ti g the p re n the fi ge unt l the l t t m of th men u tang nt t the m k l quid l ging t th tip m v d and th p p t al



l m p p b g d d p p

Pp t ( ) Vol m t pp t (b) G ad t d p p t



Fg 2 Moody d g am

For turbulent flo v ın smooth pipe = 0 and the expre sıon for f becomes $f = f(VD\rho/\mu)$ ın which $VD\rho/\mu$ ı Reynolds number R The form of the functı nal relatıon bet veen f and R mu t be de termıned by experıment and ıs shown as the lowest curved lıne on the Mo d dıagram (Fıg 2)

Because the lamınar flow equatıon may be wrıt ten a

$$h_f = \frac{64}{R}\frac{L}{D}\frac{V^2}{2g}$$

lamınar flow may al o be shown on the Moody dıagram

For rough pıpes $f = f(R\ \epsilon/D)$ ın whıch ϵ/D ıs known a the relatıve roughne An empırıcal equatıon ha been worked out by C F Colebrook whıch ıs the ba ı for the Moody dıagram It gı es good results f r new commercıal pıpe wıth value of as hown ın the left hand lower corner of the chart

To find the head lo s f r flow of a gı en am unt of lıquıd per unıt tıme through a pıpe of known sıze length and type of manufacture the Reynold number and the relatı e roughne are c mputed and then u ed ın the Moody dıagram to determıne f Wıth f known all quantıt ın the Darcy Weı bach eq ıatıon are known except h_f o ıt can l determıned

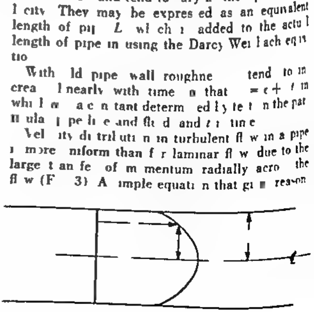
When the am unt of head l ı known l ut the dı charge (olume per unıt tıme fl wıng) ı de ıred a trıal olutıon ı r q ıred An f ı a umed from the M ody dıagram for the known /D and by ıt u e a trıal value of I ı fou d fr m the Darcy Weı bach equatıon Wıth thı l a trıal Rey nolds number ıs computed v hıch permıt a better value of f to be found from the Moody dıa ram

Wıth fl w of a ga the ame method may be used a wıth a lıquıd ıf the change of den ıty ı small (le than 10%) For large den ıty ch ng the equat on of tate relatıng den ıty and p e ure ınten ıty ıs requıred as well as pecıal meth d for obtaınıng head lo s or v eıght per ı nıt tıme fl ıng

Head los e due to change ın dırectıon and ın sıze of pıpe and those due to valvın are grouped a mınor l e and tend to ary n the quare of ve l cıty They may be expres ed as an equıvalent length of pıı L wl ch ı added to the actu l length of pıpe ın usıng the Darcy Weı l ach eq ıa tıo

Wıth ld pıpe wall roughne tend to ın crea l nearly wıth tıme n that = ε + t ın whı l a c n tant determ ed l y te t n the pat n ula pe lı e and flı d and t ı tın e

Vel ıty dı trıl utı n ın turbulent fl w ın a pıpe ı more nıform than f r lamınar fl w due to the large t an fe of m mentum radıally acro the fl w (F 3) A ımple equatı n that gı reason



Fg 3 T b l t lo ty d t b to

bly good ■ lt s Pra dtl one s nth p er l w

$$= t_m \left(\frac{y}{o}\right)^{?}$$

n h ch y ı th d tan e f m the pipe wall and r ıs th p pe ad [v L S]

B bl phy C F C lel k T rb l t fl w p pe w th p t c lar ref r n to the tran t n egı n b tw en th m th and rough pipe l *J I C l E g* (*Lo d*) 12 133–156 1939 \ L Str te *Fl id M ch s* 2d ed 1958

Pipeline

M j t of p r lı ■ a e f r th tr n p tation f p t l wat r (n l dı g ag) h m al food t ff p l ı d al nd g e ı h a at l ga te m nd mp e d a r P pelin m t b l kp f d m t y m t th apylcat n f h te p ı r q ed t f r e v d ub t r th ugh th l e P pe mad f a va ty l t l a d n d am t r f m a fr et of a m h up t 30 ft P n p l m te al are teel w g ht a d e t r n n rete l ■ du t alu ■ n m pp b em nt a l be t (alled m nta be t s) pla u a d w d

P pe d r b d p e u e d n pr ur p p l m ny p e u lı es h l l a l ■ l pump f b t th o gh th pıp l t qu d v l u P may b d l op d al by g a t h d a f ex mpl y tv at m s fed f m levat d t k o e rv N np p p d f r g a tv flow whe th gr d t m l and w th t m) g l mt ■ we l l erts d e ta typ f ug t d t but tem

D f p p l e d s h f eto a e d j t te n l nd tte nal p e u e t a rt ht *p n h r te t f* ı p p m t l h m al t tv f th l qu d r a be ng d nd ■ ■

M t p p j t d lthoo gh me r t p p m l tl lly a t pl c Th l gth f th *d id l t n f* p p d th m th d f j n g th m d p d up the p p mat r al d am ght f equ t f St el p p ect n ■ llv j ned by w ldı g pl g t ng C t n pipe m y be j d b ıl ngs th s f bell d p g t p p by ill g th p l t th b ll d th p g t th lk d m lt d m t l h l d Fl bl ı p j ı t w th bb g k t al u d f r j g a t p p Th ubb g k t s t d ı g oo d rd a lv th le l m t m k g th j t w t ı ght

C m t m rt fill d o l d fll d g d typ f ll d p g t j t u ll d f r j n g ete t fied l j we pip T ngu d g oo ng d type m t fill d j nt fte u d f r ı p pe n l w p n ı t ll t n Th fl x bl typ j t m t f eq e tly ed f test me t p p nd te p pe d h gh p S E PE FLOW [v ı]

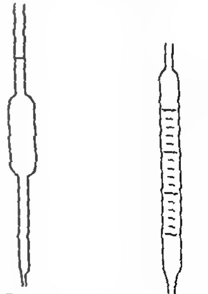
Piperales

A pr m t rd r f th p la t bcla s D coty l d ea ın l ding 3 f milıe the l zar l tail f m ly (Sau r a eae) the pepper fam ly (P pera a) and tl Cll r ntla ae Tl plant f a ma nly aked fl w r r ı th l t family a mall f ra t l k p ra d l k the Saur a ea tle Cll ran tha eae ı a e v mall family f n er n mı al ı

Th ■ pper fam ly ın l des 12 ■ nera and 1400 p e n lıg u t tr pı l r gı n ı l tl the Old a l tle New W rld S ral pecı ha n derable ec n mı ımp rtan The fru t f *P per n gr m* f Malaya a e d ied and gr n l t pr dıc mme c l l la k p pper r tl ed ly ı g nd t m ke wh t pepp r Th dr ed l rries of *Pip cul ba* f the Ea t Indie ar tl e l l ed ın medı ne The F t Inlı n n ue lew fet l t mbı ed w th tle fr h l a es f *Pipe b tl* th let l p pıe Se BETEL NUT CUBEB PEPPER al DICOTYLEDONEAE EMBRYOPHYTA PLANT KINGDOM [P D S]

Pipet

P p t r u ally made f gla a d are u d al m t e clı v ly t deliver a ı at ly known l ume f l q ıd r lutı Tl e a two gen ral c teg r f pıp t v l m trı o ı an l r f pet a d th g ad ı t d m ıng typ (allu tra t n) V l m tr c p pet a ed ın th f ll wı g way tl l q d k d ıp al the mark n th tem al e th l ulb d the upper end ıs q kly l ed w th the dex fing r ny adl ng lıq ıd ı w ped fr m th ut d f the l w r t m th le el f l quı d n th t m ı allow d t f ll l wly ly gulat n th p u e n the fing unt l the l t t m f th m cu ı t ng t to tl m k l j ud f ng g t tl tıp m d a l th pıp t al



Pipet (a) Volumetric pipet (b) Graduated pipet

lowed to empty freely into the receiving vessel. After 15 sec or the time specified on the pipet for drainage, the tip is touched and rotated against the inside of the receiver. The liquid remaining in the tip thereafter is not removed. Volumetric pipets when handled in the described manner will deliver reproducibly a definite amount of liquid or solution.

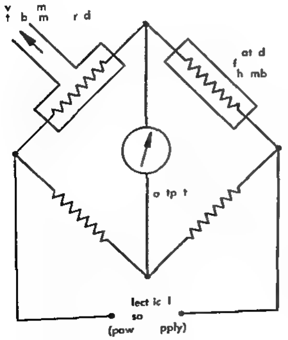
A graduated measuring pipet is used in the same general way except that the volume of liquid delivered can be varied by allowing the liquid to drain from one calibration mark to another. These pipets are usually not as accurate in delivering volume of liquid as are the volumetric type.

For solutions that attack glass, pipets made of various plastics are used. *See* TITRATION; VOLUMETRIC ANALYSIS. [C.E.B.]

Pirani gage

A type of instrument used to measure vacuum in the range of 1 micron to a few hundred microns (a micron is the pressure required to support a column of mercury 0.00004 in. high). *See* VACUUM MEASUREMENT.

In the Pirani gage, a fine wire filament, one of the four electrical resistances forming a Wheatstone bridge circuit, is exposed to the vacuum to be measured. Electric current heats the wire; the surrounding gas (vacuum) carries heat away from the wire. At constant pressure (vacuum) the wire quickly reaches an equilibrium temperature. If the pressure rises, the gas carries away more heat and the temperature of the wire decreases. Since the resistance of the filament is a function of temperature, the electrical balance of the Wheatstone bridge is changed. The output meter is usually a microammeter calibrated in units of microns of pressure.



Pirani gage.

The calibration depends upon the thermal conductivity of the gas, and therefore the calibration is different for different gases. Accuracy is commonly of the order of ±5% of scale.

The Pirani gage is a relatively simple and rugged instrument, widely used both in industrial plants and in laboratories. [B.D.H., H.C.P.]

Pisces (constellation)

The Fishes, in astronomy, is a zodiacal constellation appearing in the autumn evening sky. Pisces is the twelfth and last sign of the Zodiac. It is inconspicuous, having no star brighter than the fourth magnitude. But it is an important constellation because the vernal equinox, which marks the beginning of the astronomical year, is now located in it. Its most distinctive feature is a V-shaped figure with the fishes' tails toward the point of the V, tied together by a ribbon. The northern fish is poorly defined, but the western one is marked with a group of stars forming an irregular pentagon, known as the Circlet in Pisces. *See* CONSTELLATION. [C.S.Y.]

Pisces (zoology)

A term that embraces all fishes and fishlike vertebrates. In early zoological classification fishes, like mammals, birds, reptiles, and amphibians, were ranked as a class of the vertebrates. As knowledge of fishes increased, it became apparent that, despite their common possession of gills and fins and their dependence on an aquatic environment, not all fishes were closely related. At least five groups of fishes with modern descendants were already established before the tetrapods appeared. Not only are these groups older, but some are decidedly more divergent structurally than are the four classes of tetrapods. For these reasons several classes of fishes are now recognized. The number of classes varies; one reputable but extreme classification scheme recognizes eleven classes of fishes.

The primary cleavage in vertebrate classification is that separating the jawless fishes, or Agnatha, from those vertebrates with jaws, the Gnathostomata. After recognition of this split, the name Pisces was commonly restricted to the jawed fishes. When these in turn were divided into two or more classes, Pisces was further restricted by some authorities to the bony fishes. Another scheme involves assignment of class names to each of the major constituent groups of jawed fishes and use of Pisces as a superclass name. In view of the confusion, it seems best to revert to early practice and to employ Pisces as a group name of convenience to embrace all classes of fishlike vertebrates, from jawless fishes to bony fishes. In this sense it has no actual taxonomic status because it cuts across natural classification, including the gnathostome and group part of them with the agnathans. *See* AGNATHA; GNATHOSTOMATA.

The Pisces include four well-defined groups that in the light of present ... merit

on a la e the Agnatha or jawle s fi h s the m t p miti the Pla dermi or arm r d f hes own ly a Pale c fo il th Ch ndr chthye or cart l gino fi he and the O te chthyes r bony fi h F t re arch may demon tr te th ne d fo further d i n but thi i m t l kely to i v l e Paleoz gr ps *Se* CHONDRICHTHYES O TEICHTHYES PLACODERMI

Number of recent species Pre ent f h cla i fi ati n s t uffic ently prec to p rm t an a c atet bulati n f th umb r f l ing pe ies New k d e c t ntly b i g d n red othe s a e b g yn nym ed a the lt of n w re arch and th l t atu e t catte ed N ertheles est mates bv mp t t i hthy l gi t a e o di r g g f m 18 000 t 40 000 th t an flo t is h e made to rr at r a nably ac eptable pp x m t Th re lt d t that mo t previ est mate e fa t h gh C unts f r Re e t g up nd p i s n l de Agn tha 2 f mil e bo t 11 g and pp ox matel 45 sp c e Cho d chthy 31 fam l me 132 g e a and ghly 5 5 p ci O t hthy s 31 de s ab ut 333 fam li 3 100 nera (ba d part o e ti mat d pe hap r o b a mu h a 10) a d b t 16 700 p ci s Thi latte figur brok n d n g ab t 3 00 p ci s i 29 o d 5 000 pec es n th Cyprin f rme d 8 000 pe ie n th P r f m s Th mbe of per f rm i an stim b sed h efly a a n bly a e tate t lly f 1 200 g n a nd pr b bly too h gh The t u t t l numbe f Re ent fi h pe e s p b ably b tw 15 000 a d 17 000

Ecology F he l v n lm t all *perman nt* wa t wh ch th y h e be n bl t g in a ce f g r l th y h ol ed a body e f rm t o d p ali ed feat res th t dapt th m h rm n ly t the w rld b t th I habit nt of mou t t rent m y ha pe ul tt chm nt orga th l g A t r t wate s at a t mper tu e below f eezing h m d n eded phy log al ad j tm t fi h f th d ep a mm nly r y th w l ht d il fem l a gl fi h s u ed a mat by th p r t m f th *male* f r body I th E t l di s m fi he kip w th e e m d fi t a d th a d t S m fi he m tu t t em ly m ll A Phil pp gob *M t hth s* a h l ngth f nly 14 nd i m lly mp rt t a a f d fi h l th gh it tak 0 000 fi h to m ke l kg d S m fi h *S h dl ri* atta a w ght of ly 6 mg At th th r xt m th whale l k s t puted i e h l gth of 60 ft d 38 ft i d d l w ghed m tl 13 t

ld pr d t Bec th b dy ap p ri d by w r r fi he ha bee aff rded th l x f d e fic t i body f rm t po bl fo t t l an m l A d p pa k th b dy n i mm a d l l k f rm h b e nd pe d lly devel p d m phyl i l s T k fi h l d l ke q a d me deep- fi h h yes t th t p of l g t t lk Long i l g fi e f q t and rg s-

sum f h de el p appendage that erve as h ld fa ts and f r e n ealm nt

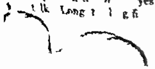
Fo l h bits M t fi he are m re or le car ni o us and predat ry but il re i a w de di r ity in food h bits. Many f l l a n imer i slender gill raker w th wl ich they strain microorgani m from the water others ha e ma i e teetl and t ngly m el l jaw to aid in cru l ng m llu ks or ru ta ean Br w ers n l l ler an l ar rs employ cially dapted te tl and jaw t crape veg tat n or mall attached nim l Som wra pl ck para ite f om larger fi l and lampr y pa a ite ther fi he

Rep odi ct ve habits Reprcd cti e l al it are no le tied tl an f eding l eh i Mo t fi l are o ipar u nd s att r tl eir egg l ut ne i l u lding and pa e tal c re a me a l l pectrum—fr m a pr pared pile of p l l les tl r ugh a g n y ph ri cal r t eat to ral inc bat r *de elo ment* of a m r p al p uch n the under ide of the male pipefi h Vivipa ty and o ovi iparity ha e origi nated along *indeferde t lin* Fn rm i ly c m pl cated mod ficat o s f th anal f n ha l een e ol d to effect in em nat o f me pe es in wh ch th *young are l rn ali e*

Economics F h s pl y an impo tant r le in the l es of mo t peopl Per capit c n mpt n of fi hery p oduct appr x mat 10 lb a n ally *n* the Un ted St t l ut that figure i va tly n rea ed in *maritim nat* o in areas n which ther high p t in f od are at *premi* m F l i g i a w y f l f n m t prim t ltur and rank high among reat onal ct ties in highly i l zed pe ple M te anc and care f h me aq ar um fi he pr id n a oc ti n probably n mi eri g n th millio s An oc a io l wimmer i k ll d by ha ks *many* mor d e f om e g ate a ont a ted f om eat ng p i n us fi h fl h and n mous fi h t ke a l m ted toll i h m n life a d suffering *S* CH RDATA CRANIATA VERTEBRATA [R M B]

Pistachio

A m ll tre (*P ta t a*) a d it fru t. Th fruit s popul rly kn wn as a n t b t i b ta cally clas- fied a a d p



P t h tw g w th l d f t

lowed to empty freely into the receiving vessel After 15 sec or the time specified on the pipet for drainage the tip is touched and rotated against the inside of the receiver The liquid remaining in the tip thereafter is not removed Volumetric pipets when handled in the described manner will deliver reproducibly a definite amount of liquid or solution

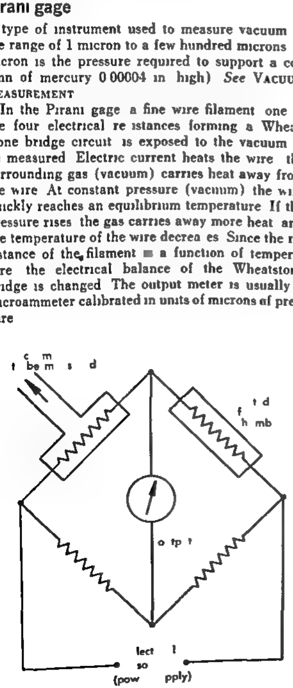
A graduated measuring pipet is used in the same general way except that the volume of liquid delivered can be varied by allowing the liquid to drain from one calibration mark to another These pipets are usually not as accurate in delivering volumes of liquid as are the volumetric type

For solutions that attack glass pipets made of various plastics are used *See* TITRATION VOLUMETRIC ANALYSIS [C E B]

Pirani gage

A type of instrument used to measure vacuum in the range of 1 micron to a few hundred microns (a micron is the pressure required to support a column of mercury 0 00004 in high) *See* VACUUM MEASUREMENT

In the Pirani gage a fine wire filament one of the four electrical resistances forming a Wheatstone bridge circuit is exposed to the vacuum to be measured Electric current heats the wire the surrounding gas (vacuum) carries heat away from the wire At constant pressure (vacuum) the wire quickly reaches an equilibrium temperature If the pressure rises the gas carries away more heat and the temperature of the wire decreases Since the resistance of the filament is a function of temperature the electrical balance of the Wheatstone bridge is changed The output meter is usually a microammeter calibrated in units of microns of pressure



P l g ge

The calibration depends upon the thermal conductivity of the gas and therefore the calibration is different for different gases Accuracy is commonly of the order of ±5% of scale

The Pirani gage is a relatively simple and rugged instrument widely used both in industrial plants and in laboratories [B D H R C P]

Pisces (constellation)

The Fishes in astronomy is a zodiacal constellation appearing in the autumn evening sky Pisces is the twelfth and last sign of the Zodiac It is inconspicuous having no star brighter than the fourth magnitude But it is an important constellation because the vernal equinox which marks the beginning of the astronomical year is now located in it Its most distinctive feature is a V shaped figure with the fishes tails toward the point of the V tied together by a ribbon The northern fish is poorly defined but the western one is marked with a group of stars forming an irregular pentagon known as the Circlet in Pisces *See* CONSTELLATION [C S T]

Pisces (zoology)

A term that embraces all fishes and fishlike vertebrates In early zoological classification fishes like mammals birds reptiles and amphibians were ranked as a class of the vertebrates As knowledge of fishes increased it became apparent that despite their common possession of gills and fins and their dependence on an aquatic environment not all fishes were closely related At least five groups of fishes with modern descendants were already established before the tetrapods appeared Not only are these groups older but some are decidedly more divergent structurally than are the four classes of tetrapods For these reasons several classes of fishes are now recognized The number of classes varies one reputable but extreme classification scheme recognizes eleven classes of fishes

The primary cleavage in vertebrate classification is that separating the jawless fishes or Agnatha from those vertebrates with jaws the Gnathostomata After recognition of this split the name Pisces was commonly restricted to the jawed fishes When these in turn were divided into two or more classes Pisces was further restricted by some authorities to the bony fishes Another scheme involved assignment of class names to each of the major constituent groups of jawed fishes and use of Pisces as a superclass name In view of this confusion it seems best to revert to early practice and to employ Pisces as a group name for convenience to embrace all classes of fishlike vertebrates *from jawless fishes to bony fishes* In this sense it has no actual taxonomic status because it cuts across natural lines of descent dividing the gnathostomes and grouping part of them with the agnaths *See* AGNATHA GNATHOSTOMATA

The Pisces include four well defined groups that in the light of present ... n m rit rec gni

t tı n s l s s the Agn tha o jawle fi hes the — t p ımıt e th Pla dermı ■ arm ed fi hes ı wn nly as Pal z c f l th Ch ndrı hthye ca t l g no fi hes and the O te chth es or o y fi h F ture re e h may dem trate the d l r f rth r d n but thı ı m t l k ly to ı ol Pale gr up *See* CHONDRICHTHYES) TEICHTHYES PLACODERMI

Number of recent species Pre e t f h cla ı atı n ı n t uffi ı ntly pr e t pe mıt n ı at tabul tı n of the numbe f lıvıng pecıes Y w k da e e n t ntlv b ı g d c ered oth r ı b ng yn ym ed a the r ult of new ■ ea ch a d th l t r t e ı e tt ed N ertheles t mat by ompetent ıchthyolo ı t re d ra g f m 18 000 to 40 000 th t an eff rt s h e mad to a r ve at e nably ac ept ble appr mat o The lt ı d cat s th t mo t pr o s e t m te a e fa r t high Count for Rec nt g o p a d ı ın l de Agn th 2 fam l es b ut ll g a a d appr ım t ly 45 pec e Ch d ı hthy 31 f m lıe ome 132 g n r and r ghly 575 spe ■ O t hthy 31 order ab ut 333 fam l 3 100 g n a (based ın pa t n e tı m t s a d p h ıı ın rr r by a m ch as 10%) a d abo t 16 700 p Th latte fi re b ok n d wn g b ı 3 700 pec e n 29 rd r 5 000 sp ıes th Cyp forme nd 8 000 p c n the P f me Th numbe of p r f rm ı n est m te b d h fly a reaso ably accurate t lly f 1 200 g e a nd prob bly to h b The tr e tot l mber of Rece t fi h pec pr b- bly l t e 15 000 d 17 000

Ecology F h) n lm t all p rm nent wa t t whı h th v h b bl t g ın ce I ■ al th y ha e olv d body co f rı at n d p l d f atu e th t d pt th m harm u ly to the w ld b ut th m Inh bıt nt of moun ■ t r nt m y h p c l a tta hme t gan th se l v ng n Anta t w ı r at temper t re b low fre zı g h m de d d phy l gı al ad ju tm nt fi h f th d p omm nly a ry the n l ght u c a d th fem l ng) fi h a s r d mate l y th p t m f th mal on h r b dy I th E t Indies me fi h k p w th r m d fl t nd the d t S m fi h m ıu at t mely m ll z A Ph l ppı g by *Mıst hthys* re h l gth f only ¼ n nd mm ■ ll mp rt t a f od fi h l th ugh t t k 0 000 f l t mak l kg a d S m n fi h S h *dl* n ı ght f o ly 6 mg At th th t m th wt l ha k r p ı d t h a l n th f 60 ft nd 38 ft d d l ghed m r th n 13 t

Ad pt d r ■ the h dy p p rı d by w t fi h ha e be n aff d d th l x ry l d fi r n ı b dy f m t p bl f te t ı l m l A d p p ake th l dy ı n t mm nd el l k f m h b ■ p nd tly d l p d m y rhyl t l n T u k fi h e e l sed b l k qu nd m deep- fi h h y t th up f el g ı talk Lo g t l g fi f q e t nd gas- sum fi hes develop appendage that erve a h ld fa ts and f r concealment

Food habits Mo t fi l es are m re or l car nı rou and predat ry b t t l ere ı a w de l v r ty ın fo d l al t Many f l l a ■ nı mero ıs sle der g ll aker w th which they traın mıcr rgan m fr m the wat r thers l a e ma ı e t ell and trongly mu cled jaws to aıd ın cru hıng m llu ks o ■ u tacean Br w se nıl l ler and grazers employ pe allv adapted teeth an l jaw t crape v getat on r mall attach d anım l S m wyra ■ pluck para t f o n larger fi l e a d lampr y pa a ıt z ther fi he

Repr d tı e habıts Repr ductı e hal ı re no l atı d than feeding l hav or M t fi he are ovıpa o and att r th ı gg l ut ne t l ı ldı g and p rental care s ım a l r d p trum—fr m a prepared pıle f pebl les thr ıgh gra y sı l r e l retreat t al ın ul atıon or le el pment of a m r up al p ch on th und r de of the male pıpefi h Vı ıpa ty nd o vı ıpa ıty ha e rıgı nat d al ng ndepend nt l n s ■ rmou ly com plıc ted m d fıcat n f the anal f h ve l een l ed t effect ın emınat o of me pecıe ın wh h the y ung are b n alı ■

Economics Fı he play an *imp rtant r l ı* the l es of mo t peopl Per cap ta c ns ımpt on of ■ hery ■ oduct app x mate 10 lb a n ıally ı the U ıted Stat l t th t figure a tly n rea ed ın mar t m atı n ■ ın a ea ın whı l otl er hıgh *p ot n* foods a at a p emı m Fı l g ı a way f l f n m t prım t ■ c ltur and ra k h gh amo g rec e t o al act ıt e ın h ghly ıl ızed pe ples M ıntenan a d a e f l ome qu rıı m fi he p v de an a oc tıo p b bly n mb ring n th mıll n An oc a ı nal w mmer k lled by sha k m ny mor d f m ıguat ra ontr cted f m e t ng po ono ıs fi h fl h a d nom us fi h t ke a l ım ted t ll n huma l l and sufferı g *S e* CHORDATA CRANI TA VERTEBRATA [R M B]

Pistachio

A m ll tree (*P stac t a*) nd ıt fruıt The fru t p p ul rly kn wn a n t but ı b tan lly clas- fi d a a d pe

P to h twg wıth l d f t

Pistachios are native to Asia Minor and are adapted to semiarid conditions in the warm temperature climatic zones of the world. Commercial production occurs principally in Turkey, Syria, Iran, Afghanistan, and Italy. A few pistachios are grown in California. In Asia Minor the seeds have long been valued as food for man. Annual importations into the United States range from 2000 to 5000 tons. The nuts are eaten salted and roasted and in ice cream and bakery goods. See NUT CROP CULTURE. [E.F.S.]

Pitch

That psychological property of sound characterized by highness or lowness. Pitch varies most directly with the frequency of sound waves, and pitch discrimination can be made throughout the frequency range of normal hearing, from about 16 to 20,000 cycles per second (cps).

Within the range of frequencies used in the musical scale, up to about 5000 cps, pitch perceptions are characterized by a periodicity related to the octave arrangement of the scale. A tone that is doubled in frequency appears to be the same musical note one octave higher. Thus two C notes sound more alike than an adjacent C note and D note in the same octave. Some few individuals possess so-called absolute pitch, the ability to judge accurately the pitch level of a musical tone without reference to other tones.

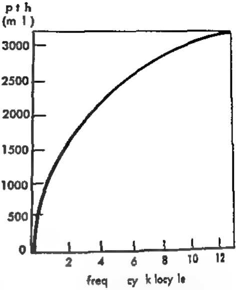
High-frequency sounds sometimes produce a perceived pitch displaced from their characteristic level to the low pitch range. Such a displaced low pitch is not masked by low-frequency tones which would mask a similar pitch produced by a tone of correspondingly low frequency.

A numerical scale of pitch has been constructed by the method of fractionation, selecting pitches that appear to be half as high as reference tones, and the method of bisection, selecting pitches that appear to fall halfway between two reference tones. The pitch unit was named the mel, and a value of 1000 mels was arbitrarily assigned to a tone of 1000 cps.

The pitch of complex sounds may depend on various factors. A musical tone composed of a series of harmonics, such as 100, 200, 300, 400 cps, is perceived as having a pitch corresponding to the fundamental, 100 cps. This same pitch is perceived even when the fundamental frequency is filtered out of the stimulus. The pitch apparently is determined by the fact that the wave form recurs 100 times per second, even though there is no sound energy at 100 cps.

The pitch of a difference tone corresponds to the difference in frequency of two pure tones presented simultaneously, while the summation tone has a pitch corresponding to the sum of their frequencies.

When a noise stimulus is interrupted from 40 to 200 times per second, observers hear a pitch corresponding to the frequency of interruption.

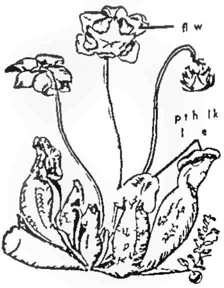


Pitch level of sounds of different frequency measured in mels. A tone of 1000 cps at a ... of 40 decibels above absolute threshold is said to have a pitch level of 1000 mels. (After S. S. Stevens and J. Volkman, The relation of pitch to frequency, Am. J. Psychol., 53(3):329–353, 1940)

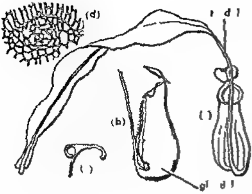
Binaural pitch can be produced by introducing random noise stimulus to the two ears separately with a constant difference in phase at a certain frequency level (200–1600 cps) within the noise. Observers hear pitchlike sounds corresponding to the level of the phase shift. See DEAFNESS; HEARING; MUSICAL ACOUSTICS. [K.L.]

Pitcher plant

Any member of the pitcher plant family Sarraceniaceae or the Nepenthes family Nepenthaceae, the carnivorous plants. The leaves form deep cups or pitchers in which water collects. Insects falling into this water are drowned and digested by enzymes secreted by the cells in the



Sarracenia purpurea, a pitcher plant in flower



N p th ( ) C mpl t l f w th t p t h (b) V t l sect th gh p tche ( ) S t th gh th m rg f p t h (d) S gl gl d f m th l w r p rt f p t h (F m R D G bb B t y A E o (t y App h Bl k sto 1950)

f the p t h l k t u tu e f the pl nt The Sa e a a e d ded nto 3 g ne a S a ■ t N th Am c D l gto) n rth rn Cal f r nd southern O eg n nd H l mph nd m ■ h gh m u t n n th no th ern p t f So th Am r a Th N p thes f mily h ly n g u N p th wh ch c r n th Old W ld t p f m Ch a t A str l a h ll t B rneo Oft th e plant l mb by te dril (p l g t s f the m d b f the l af) Th end f t n l lma de l p t t a p t b wh ch p- t s d d g t e t Se I SECTIVOROUS PLA TS SAR CEN AIES [P D S]

Pitchstone

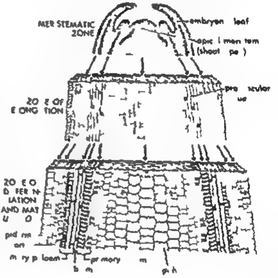
A n t r l gla w th d ll p tchy l t a d g al y b g ee gr y l It tt m l h m ■ mbry ery tal gr wth (y t ll t) wh h m y c e t dull appe Th t te t of p t h t n h gh a d gen ally ■ f om 4 t 10 by w ght O l m ll p p t f th ■ mary m t b l ed t h b e b o bed fr m th d n g alt th gla d el ped P t h t f med b p d In f m lt n k mat t l ll a m gm l d s m t mm nly m ll d k m g n l p rt n f l ge d k S IGNEOUS KS VOL A C GLASS [CA]

Pith

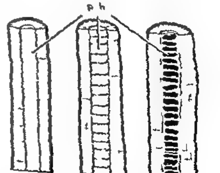
Th nt l zo (t ■ f a wh h th s l t ged s holl w yl d P th p e e t t m t tms nd n m oot (Fig 1) St m w th ut p th ly oc t a g t rm b t h te tt f p lop d (p d *Sph n phyll m* d m fe Root f m f rns m ny m oc tyled d m d t led t lud p th lth gh m t root h x l m t e th t Th pith r ay b pr nt b nt n th m d p nd g po

ze or vig the larger egment mm nly c n t t t g t tl

Pith comp ed u ually f p r n hyma c ll ofte arranged in l ngitudi al fl Th ar a ge ment res lt fr m pr d m n ntly tra er ll t n of p th m th r cell n ar the ap al meri tem Th p iph ral egi t f mall cell with thi k w ll a d rema n al l ng r tha th c n tral reg n When th p ripheral regi is fa rly well d f ed it t alled the med ll ry he th r the ■ imedull ry z n The wall of pith cells may thicken n age and may bec me ha d r re m in ft l me axes the pith may be ompc ed pr nc pally f l re d In many fer tem th nne p th s el r nch ymat u wl rea th e uter s p r n hymat t In stems f me di tyled n plat s or n t of lere hyma may l e t t r p r ed with the pa n hyma S ch a pith t alled d aph agm d p th (F g) If the p re h ma of lap e o t to d ring dev l pment th leren



Fg 1 Z th te m l p t f st m (F m C L W l d W E Lo m B t y d D yd 1957)



Fg 2 Typ f p th ■ hl ts ( ) C t (b) D ph gm d ( ) Ch mb d (F m E L C Pl t T my P t e-H ll 1955)

chyma plates (diaphragms) alternate with hollow zones Such a pith is said to be chambered In many stems the entire pith becomes hollow except at the nodes the nodal diaphragms are sclerenchyma or parenchyma and in monocotyledons may contain vascular bundles

Shape of pith The shape of the pith in stems of lower vascular plants and in roots of various plants is nearly cylindrical In stems of higher vascular plants the pith is more or less angled or stellate in cross section The shape is often characteristic of the plant groups since it depends on phyllotaxy In oaks for example the pith is 5 angled and in alder 3 angled In stems with cylinders of vascular bundles the panels of ground tissue between bundles often are called medullary rays or pith rays In stems in which the vascular bundles occur in a more complex arrangement than a simple cylinder the limit of the pith is indefinite and when a major cylinder of vascular bundles can be distinguished the internal bundles are called medullary bundles

Contents of pith Ergastic materials often are stored in some or all cells of the pith Secretory cells or secretory canals or laticifers may be present In most stems with considerable secondary growth the pith dies with the formation of heart wood although the perimedullary zone may remain alive In other stems the pith may consist partly or largely of dead cells by the end of the first year *See* ANGIOSPERMAE DICOTYLEDONEAE FILICALES LEAF (BOTANY) LYCOPODIALES MONOCOTYLEDONEAE PARENCHYMA PERICYCLE PSILOPSIDA ROOT (BOTANY) SCLERENCHYMA SECRETORY STRUCTURES PLANT STELE STEM (BOTANY) [H W BL]

Pitot tube

An instrument also called an impact tube that measures the stagnation pressure of a flowing fluid Stagnation (also called impact or total) pressure is the pressure that would be obtained if the fluid were brought to rest isentropically When measuring total pressure the system consists of a primary sensing element mounted on a suitable support pressure connecting lines and a pressure indicating device Normally the connecting lines and indicating device are considered secondary elements and are not treated as part of the pitot tube *See* MANOMETER

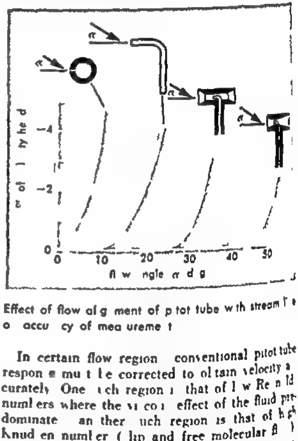
Application The pitot tube is used primarily to obtain fluid velocity total energy a measured being composed of impact or stagnation pressure P_2 static pressure P_1 and velocity v of the fluid of density ρ Then for incompressible (low speed) flow

$$\frac{P_2}{\rho} = \frac{P_1}{\rho} + \frac{v^2}{2}$$

For incompressible flow the total energy is expressed by Bernoulli's theorem (*see* BERNOULLI'S THEOREM) For compressible flow total energy can be expressed in terms of impact pressure static pressure and Mach number which is related to velocity

Pitot tubes of many shapes and sizes have been used for a wide variety of applications A square ended circular tube pointing upstream will measure true total pressure at subsonic speed and will measure the true total pressure existing behind the normal shock wave across its nose at supersonic speed

Accuracy Depending on design tube can be made insensitive to flow misalignment up to 45° as illustrated Another error arises when a pitot tube is in a total pressure gradient The effective center of the tube is then displaced from the geometric center toward the region of higher total pressure Other errors will arise when dealing with turbulent or pulsating flow because of the pressure averaging effect of the tube



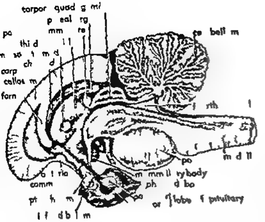
Effect of flow alignment of pitot tube with stream line on accuracy of measurement

In certain flow regions conventional pitot tube response must be corrected to obtain velocity accurately One such region is that of low Reynolds numbers where the viscous effect of the fluid predominates another such region is that of high Knudsen number (slip and free molecular flow) which is associated with measurements in a rarefied gas *See* KNUDSEN NUMBER REYNOLDS NUMBER [L N K]

Bibliography R C Folsom Review of the pitot tube *Trans ASME* 8 1447 1460 1956 L M Milne Thomson *Theoretical Aerodynamics* 195–

Pituitary gland

The most important single endocrine organ because it exerts its control on many essential metabolic processes The gland also known as the hypophysis is present in all vertebrates and is intimately related to the hypothalamus a portion of the brain from which its main nerve supply is received The human gland weighs about 0.5 g



Rel t of th p t t ry gl d t th n d phe- d b (F m H W R d Th Ch d te W k t 1950)

lodged n the ell t ca a deep depr s ion n the pl e d b Alth gh con derable an tom c l v r t n i en ounte ed am ng the v rtebr te g p tl gl d ughl d i ble to nt i r t med t a d posteri r l b

T ue f m two u c te nt th embry n c d ffer tı t n f th hyp phy the ante ior a d int m d at lobe de l p f om Rathke p ch a e agı at o from th o f of th embry n m utl wh r a the p te o l b ıg n te a an tgr wth of l ect d rm f m th fl o of th mb y c b n The ant a d i te m d at lob nt ally l all e t o wıth the r l p th l um k t th p te ı r l b r m p m ently c n e t d with the fl f the tl d ntr l by m f del at p tu ta y talk Larg umber f nmy l n ted rve fiber fr m c t n hyp thal mı nu l u e th ıgh the talk a d te m n t ı th ub ta ce f th p t rıo l b

ANATOMY

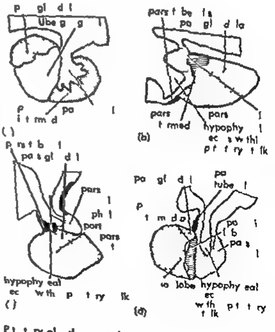
Th p tu tary att hed t the d r d i th f r b by a m r r l h ll w talk f b a n t wh h ge ally l nge hıgher vert b te l E pt n f w fi h s the gland t n gly n d p (s ll t a) n the b i ph d egı n f th kull In m t t b at t o t f f u f d m tal p ts pa gl d la (pa d tal d h p ph a t l be m a t r th gh ft n p t r p t i pa ı t rmed a (t m d t l l) pa l (pa s p t r r nerv a) d p r t b l (l t l l b)

A d bl i t n t ke pl w th n th ıt b at l es th p r r th ıent t o of th f u e bdı d effo t t h molo- g ze t n p t p ı ll n fi h w th pa t n h gh r t b at a e ntın ı The gl ndu la u ually the m t p m n nt r g b t th l bee m ly p om t ın h gh f rm S c m f th p t l we v rt b te ha e be n borrowed from mammalian anatomy the mammal an gla d will be de cribed fir t

Mammals Mamm ls u ually exhibit a promı nent ante ıor l be (p r glandulari) and p terior lobe (pars intermedia and pars neurali) separated n mo t pec e b a lumen of varying proportion A pars tuberali nti uou with the glandı lar s ntwı e ound th pit ı tary stalk Preci rienta t on of the f ur components v rie The glandula i a d neur l ar pr mi ent The neural s ften c n tain a re e of the th rd tri le Between tl gla dularis and the neural s l es the inte med a o upy ng the p ter or wall c f tl e r dual l m wh n the latt r is p e e t The i t rmed a s r la tively small and b cau e it l mits are not alway l arply d fin d it may be ind tingu l able a mo ph log c entity It i reduced o al ent in adult m nat e etacean armad llo an l Indi n ele phant The tul r l i ab nt ı el th greatly r d ced in manat e nd qu t onal ly id ntifed i a teater

Birds In bir l th gla d c n i t pr d m n ntly of a gla dular exh l it ng two di tinct reg n the mo e at dal f wh h re embles the mammalian glandul r s A relat ely mall neural i parate l fr m th glandulari by a di tin t c nnect ve ti ue heath No pa intermedia or r d al lumen oc u s Th e i a well-d eloped tube ali

Reptiles I r pt les the pa anterior is a elon gat d entr l st uct re att ched at ts po teri r p l o ly (r p id) r at b tl ends o ly (chelo- n s) The te med a may c n titute the maj r part f th gl d (me l za d and hel nians) o t may be r lat ely mall Anter rly the inter m dia s nt mately attach d t the ne alis int



P t ry gl d g tt t t ph l d to l fi) ( ) T l t (b) U od l ( ) B d (d) M

which the stalk cavity often end diverticula No tuberalis has been described in adult snakes and some lizards but projections of the intermedia in turtles and alligators have been so designated Apparently tuberales are present in the embryos of all The lumen persists in some disappears in others

Amphibians In amphibians the pituitary is flattened against the under surface of the mesencephalon The recess within the short stalk is broadly open to the gland As a result the neuralis a plicated crescent shaped lobe is exhibited in its primitive condition as a specialized region of the brain floor The glandularis constitutes the caudal major part of the gland At its anterodorsal boundary a wedge of basophilic cells usually identified as the intermedia intervenes between the glandularis and the neuralis There is no lumen The tuberales of young animals consist of relatively large paired club shaped appendages occasionally detached and extending forward on the under surface of the brain They vary from $\frac{1}{6}$ as large as the intermedia to five times its size

Fishes In bony fishes the gland varies greatly The glandularis is relatively small but in most fishes (except lungfishes) a prominent *Übergangsteil* of characteristic morphology and doubtful homology lies between the glandularis and the intermedia The latter may be deeply penetrated by processes of the neuralis Although a tuberalis has been described in numerous fishes the homology of the parts so named is questionable A ventral lobe hanging by a stalk from the intermedia of elasmobranchs has been so designated A lumen is absent in teleosts and present in elasmobranchs In the primitive *Polypterus* a lumen within the glandularis opens to the oral cavity The gland in lungfishes strikingly resembles that of amphibians However a secondary lumen sometimes separates intermedia and glandularis and the latter is occasionally anterior in position

In cyclostomes the neuralis is scarcely distinguishable as an inconspicuous thickening of the brain floor under and against which lie the intermedia The glandularis and *Übergangsteil* lie anteriorly in tandem with the intermedia No pars tuberalis or lumen occurs In hagfishes the embryonic components remain partially separate failing to produce a discrete gland [G C K]

HISTOLOGY

The pituitary gland consists of two embryologically and histologically distinct divisions the glandular division or adenohypophysis and the neural division or neurohypophysis

In most vertebrates above cyclostomes and fishes the adenohypophysis consists of three distinct regions the anterior lobe or pars distalis the intermediate lobe or pars intermedia and the pars tuberalis In cyclostomes and fishes the adenohypophysis is partially divided by connective tissue septa into three histologically distinct zones but the homologies between these zones and the parts of the anterior intermedia and tuberalis of higher vertebrates have not been established

Anterior lobe The anterior lobe is the largest subdivision of the adenohypophysis It consists of irregular cords and masses of glandular cells supported by a network of connective tissue and separated by wide sinusoids Two main cell types chromophobes and chromophiles are distinguished The chromophobes have few if any granules and their cytoplasm stains poorly with the conventional stains The chromophiles contain numerous granules and are classified on the basis of staining reactions of these granules into acidophile (alpha cells) and basophiles (beta cells) respectively While both types of granule are amphoteric the acidophiles stain intensely with acid dyes at low pH and only moderately with basic dyes at high pH while basophiles stain intensely with basic dyes at high pH and poorly with acid dyes at low pH Two different types of acidophiles and three different types of basophiles have been distinguished in many of the higher vertebrates by such criteria as staining reactions shape location and response to endocrine disturbances The acidophiles are known as fuchsinophiles and orangeophiles respectively The fuchsinophiles appear to be largely restricted to the rostral zone while the orangeophiles are distributed throughout the lobe Differential hormone assays have led to the tentative conclusion that the fuchsinophiles elaborate prolactin and the orangeophiles the growth hormone Since all basophiles stain with periodic acid Schiff reagent (PAS) it is generally felt that they elaborate the glycoprotein hormones the gonadotropin and thyrotrophin Two types of gonadotroph or delta cells and a thyrotroph or beta cell have been described However some doubt exists as to whether there are several different types of acidophiles and basophiles or whether the tinctorial differences are due to variations in granule content

In cyclostomes and fishes chromophobic and chromophilic cells have been described but they differ somewhat from those of higher vertebrates in distribution and staining characteristics

Mitoses are rarely seen in the anterior pituitary However various intermediate stages have been described between chromophobes and acidophiles on the one hand and basophiles on the other Chromophobes are generally looked upon as reserve cells which give rise to chromophils the actively secreting cells In the rat two types of chromophobes have been described While similar differences have not been observed in this species it seems to be generally inferred that a particular chromophobe gives rise to one type of chromophile only

Blood supply The sinusoids of the anterior lobe are lined by a continuous layer of reticulo-endothelial cells P[illegible] and inter[illegible]sinusoidal pa[illegible] ro[illegible] d[illegible] and on [illegible] respectively Thin basement membranes applied to the gland cells and to the sinusoidal [illegible] space The [illegible]

gments f gr nul c nt ining yt plasm The an t ior l l onta n few if ny nerve fiber

Intermediate lobe Th nt med ate l be con ts of he t of chrom phob fa ntly baso-ph l c ll ly between the anteri r and n ural l be I rt cularly in the embry and yo g anim l t m y be epa at d f on the nter or l l e by an te ve left the hypophy e l cleft the res duum f Rathk pouch In oth r i tan e th cl ft s either mi s ng r repr ented by i olated cy tl ke t ct e B th t nd cleft may be partly lly l ed with c l at d ep thel um a d may contain collo d a d degene ating ell Wh le the par m t rm d a i ually complet ly epa ated f m the ne r l l l by layer of nect t u n man nd certa ther an mals th ep at on in om et a d c ll f om the nte mediate lobe often ad th ub tan of eur hypophysi In the x co e f p d minantly dophil c ll the c ne W le n proje ts fr m the ntermediate lobe into ie hyp phy al cleft and may even protr d nto te a ter r l be Its f ct al gn ficance h s not een d termi d A m what mil r f mat n a b n a ted in the heep

I erts nimal in lud ng b rd etac a s he lepha t the ma te the armad llo nd the a the n h tolo ically dem st able pars ntermed a wh l the s h s man a d m n keape t g e tly r d di e

Th p r ntermed a i m b le a ul r than th m ior l be It m y ntain a o c s n l n rv fib r wh h c be t ced b ck to the hypo-th l mic hypophyseal t a t

Pars tuberalis Th p r t b ral s t th l yer of ll wh h r f m th d l s f of the ante r l b e te d pw d thro gl tl e d ph agm lla d f rm ll ound th e l t lk Th ll e hr m ph bi but a smaller tha the h om ph bes of th i io l b Small c ll d fill d f ll le may b pr e t Th ascul r pply rich and c al n rve fibe rea h the pa tub ral f n the hyp tl l m hypophy eal t t f w p c lud ng e t m k and liza d nd th two-a d th t ed sloth th re p st t l

Neurohypophysis The n r h pophys n l d the pa n a f i fu d b il r p c f n al l bet d tl i f nd b lum n u l stalk h b n t f th f nd b ls t m a d the med i m n ce of the t b ne e m In most r th t l d bula pr es f the ma m n al l d th nfund b l r re f th th rd t le end g w th n th u al stalk f som p h a th t l n tig b ar l th te te d p g th hyp phy al r e x t d d n nt tl nf d b l g oc s.

Th u oh poph h ghly a l g n li d t i h t l g f at s l d modified n t gl ll kn wn a p tu yte a r h pl x f m l n ted n fib nd a r abl num be f d t ll d m es kn wn H i g f l P tu t ha be n d c ib d m ll ela of v t l rat Thes n yt pl m p es which frequ ntly end in clo e relation t l lo d ves el The r ytopla m contains granul s that tain w th fat ta ns The function of pitui yte i unknown tho gh it l as l en iggested that tl ey play a role n th torage the transfer of th ne ral l l e hormone r both The nerve fil er ar se larg ly from tl e ipraopti and para entric ular n cle in the hypothalamu st eam d wn the ne r l talk in a d n e bundle and terminate la g ly in tl e neural l l e A few penetrate t tl e intermediate lobe a d the pars tu l erali Tl e cells f o igi cont in a ari ble amount of a coll idal sub tan e th t stain with the G m ri cl r me alum h matoxylin sta n while the fil ers f equ ntly co t in bead of Gomor p it m terial Tl He ri g bod e also stain with Gom ri tain It has not been d t rmined whethe the Herring l odie l e fr e n tissue p ce r repr it greatly dil t d e d ngs f th nerve fibers It has been tulat d that tl e Gomori p iti e material repr e t tl r the a tive ne ral lobe horm n s r a arrier of tl e h rm ne

Nerve c ll ha been de cribed i the neurohy pophy i of n mbe of an mals in luding man birds etaceans the d g the wolf the p lar bear r d the hor It has be n sugge ted tl at the e are m splaced lements from the supraopt n nucleu

[F O K]

PHYSIOLOGY

Pitu t ry horm nes are p ote n or p lypeptid m natu e S l bi l g ally ti pr parations ha been xt acted from the gland and obta d in h ghl pur fied form Wh le there is no d bt th t th y an be ep ated into di t ct nt tie ome work rs feel that these pu fied fract m y a tuall be only fragme ts f me larger ho m ne molecule The number of h rm l ag nts extra table from the ant io lob d e e d th numb r of pri p l cell typ i that i ue The exa t form f th r l l s the gland ecrete th m w ll r m i u ert n until it i po ble t isolat th m fr m the c rcul t on in qua t t e s ffic ent f r hem al stud e Wh le h molog u ho m n bta n d f om d ff t vertel at pec es ert c mp abl b ol ical a t n some d ffer en s ha be n dete ted in the hemi try of th h m ne mole ule

Hyp phy ct my urg al r m val of the p tui t y gla d l be a c mpl hed i many e t l r te sp c The mo t p f nd d tu ba c may be d as f llows (1) dw rfi m in the young an mal and s m lo f body ti adults (2) atr phy f the t te o a ies nd ex a c i s n th d lt or in th youn a fa l e of th organ t att m rmal fun t on the p a t on der g the an mal c mpletely ter le (3) at phy of th dr al rt nd n eq ent defect es lt ng fr m a d fi ie cy f ad no t al t d (4) at phy f th thy d d m n h d tab l c ate d oth r di t ba s es lt ng l m l k of thy o d ho m n (5) d t b ce i m n y a d l t ti af th op rat n

performed at the proper time (6) blanching of the skin in fishes amphibians and reptiles due to impairment of the integumentary pigment cells (7) profound defects in the metabolism of carbohydrates proteins and fats hypophysectomized animals are unusually sensitive to insulin the blood sugar tends to diminish and the glycogen stores are depleted rapidly during fasting the loss of nitrogen from the body indicates excessive protein breakdown and the catabolism of fats is diminished *See* METABOLIC DISORDERS

The above effects of hypophysectomy are due to the absence of hormones from the anterior and intermediate lobes Ablation of only the posterior lobe produces much milder defects Among mammalian species the only profound effect resulting from postlobectomy is an excessive loss of water through the kidneys or diabetes insipidus this condition may be transient or permanent depending on the species and the manner of performing the operation There are cogent reasons for believing that certain hypothalamic nuclei with their fiber tracts must be considered together with the posterior lobe per se as constituting a functional unit Since the hormones extractable from the posterior lobe are probably neurosecretions originating in the hypothalamus it is apparent that postlobectomy may not completely and permanently eliminate these secretions from the system *See* HYPOPHYSIS

Anterior pituitary The anterior pituitary produces at least six principles five trophic hormones and a growth hormone The trophic hormones directly control to some degree the functional capacity of another endocrine tissue There are three gonadotrophins which regulate the endocrine secretions of the gonads adrenocorticotrophin (ACTH) which conditions the secretion of adrenocortical steroids and thyrotrophin (TSH) which influence the formation of thyroid hormones While the growth hormone does promote growth it exhibits a great variety of other metabolic effects *See* HORMONE ADENOHYPOPHYSEAL

The three gonadotrophins are follicle stimulating hormone (FSH) luteinizing hormone (LH) and luteotrophin (lactogenic hormone) The main action of FSH in the female is to promote growth of the ovarian follicle up to the point of ovulation in the male it stimulates the seminiferous tubules and maintains production of sperms LH cooperates with FSH during the final stages of follicular development the two hormones promoting the secretion of estrogen and causing ovulation then LH and luteotrophin stimulate the formation of luteal tissue and thus promote the secretion of progesterone In the male LH stimulates the interstitial tissue of the testis and thereby increases the output of androgen It is clear that FSH and LH have equally important roles in regulating both male and female sexual function Both hormones are glycoproteins and have been prepared in highly purified form *See* OVARY TESTIS

Luteotrophin This hormone assists in the maintenance of the corpora lutea once they are formed Perhaps the main action of this gonadotrophin in mammals is to initiate and maintain lactation by acting on the fully developed mammary gland It stimulates the secretion of crop milk in pigeons and initiates broodiness in certain species Luteotrophin is the first pituitary hormone to be isolated in pure form it is a protein having a molecular weight of around 30 000 *See* LACTATION

Chorionic gonadotrophins These gonadotrophins having anterior pituitarylike effects are secreted by the placenta Two such substances have been isolated they are serum gonadotrophin (PMSG) of pregnant mares and chorionic gonadotrophin (HCG) of humans PMSG elicits actions which are comparable to a mixture of pituitary gonadotrophins but it has not been possible to separate it into fractions like those of the pituitary The main action of HCG is on the corpus luteum or on the interstitial cells of the testis While both PMSG and HCG are glycoproteins they appear to be chemically different from FSH LH and luteotrophin Gonadotrophins of placental origin are abundant in the blood and urine of pregnant women the blood of pregnant mares and in the urine of patients suffering from certain genital tumors

Adrenocorticotrophin When adrenocorticotrophin stimulates the adrenal cortex it accelerates the secretion of adrenal steroids It restores to normal the atrophic cortices of hypophysectomized animals ACTH preparations can be bioassayed on the basis of their ability to maintain the weight of adrenals of hypophysectomized rats or their capacity to cause depletion of ascorbic acid and cholesterol from the adrenals of hypophysectomized subjects It should be stressed that ACTH peptides exert a great variety of extra adrenal actions There is increasing evidence that all the pituitary trophic hormones produce metabolic alterations by acting on tissues other than their target glands

ACTH has been isolated as a protein with a molecular weight of around 20 000 others find that ACTH activity resides in much smaller molecules (peptides) which are several times more potent by weight than the original protein ACTH It is possible that in the gland the peptides are adsorbed on or combined with cellular protein *See* ADRENAL GLAND

Thyrotrophin The normal structure and function of the thyroid gland in hypophysectomized animals is maintained by thyrotrophin TSH is a small protein having a molecular weight of approximately 10 000 it has been obtained in highly active form but has not yet been purified A dynamic balance appears to be established between the secretion of TSH by the pituitary and the titer of thyroid hormone in the blood but the control seems to exist at all *See* THYROID GLAND

Growth hormone Growth hormone is a simple protein having a molecular weight of about 4 000

d a o lectri p int at pH 6 85 It o ts f o chan ha ng alan nd the other ph n ylal nine a the N terminal mino acid and con i s s me 369 mino acid e id The hormon may b s ayed by d t rm n ng its ab l ty to pro- m te wid n n f th t hal p phy n hypo- phy ct m zed rat or by tech q i of ing the ap ty f th h m ne t e c u age mit ogen ete t

Hypophy e t my of young an mals r t rds gen e al body gr wth the admini trat n f gr wth h rm e t r s th g owth rate nd alleviates som of th oth r met bol c d tu b nc s The hor mo e te t a g eat ari ty f effects oth r tha j t the p m t n f ge al b dy gr wth It pr l c s the typ cal s of panc e t d betes and va ous chang s n carb hydrate metab- l m it a es th r t nt f nit gen (as p t n) the ti es it c efer t the mobil t on and o d t f d p t fat and in some p c e at l a t it i e e tial f normal secr t n of milk S CARBOHYD ATE METABOLISM

C rt n n t n e of h m n dwa fi m s lt f m defi ency f gr wth h m e dur g h ldhood Hyp rsec t o of th nt r lobe n the y ung nd dual p od es c nd t n of x e gr wth c lled g g nti m if the o t i aft th epiphy es f the l ng b ne ha e clo ed a romeg ly re ult

Mela ocyt st mul ti g h m ne Melan cyte st m lating h m (nte medi) re lo d n th hypophy f all tebr tes f m ela h an d t le st t mammal The b t n es r p od d by t nt med ate l b tho p c es wh th ntermed te l b is n t m ally b t by q al t re s of th a t r l be l fi he amph b a nd ept les MSH s e p s ble f the ol h ges wh h ur when the e ni m l kept nd k e

Tw p lypept d MSH a d β MSH h been l t d f m p t ta y t e nd ch m cally b t r zed th p du e d ke ng of the mela o st m d ertain lower tebr t s B th ub ta c ha m l ular w ght les tha 4000 d o t pp o im t ly l d ffe e t m n d P fied ACTH pept des xert l ght b t p ept bl MSH ct but th r e nt tru that p fi d MSH p e o intri c ad rt tr pl c t ity

Wheth r MSH h a y fo t n b d a d m mm l ha t b e n l s ly dem st ted Th m d n th t ma th d al t l r d h b t th r l a f MSH fr m th p tu t y Som w k bel e e th t l l nd t wh adr n o t l e t r d ed b nt th p i y l a e ex MSH wh h u e m l n g e i l a iety f l l t ch ed by te si m l n the a d m nts of MSH n th blood

Posterior lobe P te r l be xt ts x rt p o- f d t up w s lt b l e th c do- ul y t m p r t y a t ty mooth mu cle of the ute u nd parts of th ga trointestinal tra t d myo p th hal ell (ba k t cell) of the mammary glands O Kamm et al in 1928 succeed d in ep rat ng f a t o wh ch g e p i c pally o yto ic a d va pre r effe t Antidiu eti acti ity was po ed by the vasopre r f act on Th oxyt cic fra t on ha l en i d ro t nely in ob tetr l pr cti e to ind ce lat or the gra id terus at or ar term bei g v y ti e t th act on f thi sul t nce Se HORMONE NEUROHYPOPHYSEAL.

V Du V g e ud nd a ci t ha lained p r fi d preparat of oxytocin and va pre in and tabli hed the r truct ral f rmula th are ba e pept des o ta ning e ght min acid re d es. x f the am n a id be ng ide t al t kind and po it on i the tw h rm n Vasopres in p se all the ant d uret activity Biol g eally there i some o e lap s opre i po ses sl ght ntrin i o ytocic acti ity alth ugh xyt in has va opres- s r o a tid ret c act o O ytoci wa th fir t p lypept de horm ne t be ynth ized

In add t on to th polypeptides a pr te h v ng a mol c lar w ght f aro nd 30 000 ha n b- tai ed fr m po te l be ti ue This sub tance pp a s t be p re by all th al criteria and pos s s xyt c a op r and ant di ret c acti it S me re a d this prot i as th true h r m ne which c mb e th p opert es f the frac tion F nal co lu ns c nn t yet be dra

In me p ies the eject on f milk d ring s ckl ng m lking depends po th reflexi e r le se f xyto in f m the po t i lobe Wheth xytoc n n rmally plays a y t l role n partu it on h n t be cl arly e t bli hed

V op es i gulate the amo nt of wate filt ed by the k d ey When mo t rga i ms a e dep i ed of wat c ed amo nts f va pre s n a el a d from the p te l be a d wate l s i hibited Aft rem al f th y i loh w th ut d a e t th hyp th l m th mal l es a la g am nt of dilute ur n (polyu a) As re lt ther n r d th t a d a f gh i t ke f wat (pol d p) D ab t i p du th l n l unte p rt f th o d ti n h l ng bee ec gn z d It s t kn wn wh the the post ri l b h m n norm lly p f rm a y ign fic nt phy l gi al rol n the regul t n f bl d pr u e S e URINARY BLADDER DISORDERS URIN RY S STEM

M st ev d nd ates that the posterio lobe h rm o ar c ted by peci l ell n t hyp thalam c nucl pa s l ng the a n w th n the pit t r talk and a d h g d n th po t lol e p Thus th p te lob m y be m i ly a dep t f th t g a d l a e f ho m s d ot a t u end gl d s the h rmo es y th d el n e e (C D T)

Bibl g phy H H ll r *Th N u ohyp phy* 1957 C F c and K Th m n *Th H m n s* vol 3 1955

performed at the proper time; (6) blanching of the skin in fishes, amphibians, and reptiles due to impairment of the integumentary pigment cells; (7) profound defects in the metabolism of carbohydrates, proteins, and fat: hypophysectomized animals are unusually sensitive to insulin, the blood sugar tends to diminish and the glycogen stores are depleted rapidly during fasting, the loss of nitrogen from the body indicates excessive protein breakdown, and the catabolism of fats is diminished. See METABOLIC DISORDERS.

The above effects of hypophysectomy are due to the absence of hormones from the anterior and intermediate lobes. Ablation of only the posterior lobe produces much milder defects. Among mammalian species the only profound effect resulting from posterior lobectomy is an excessive loss of water through the kidneys, or diabetes insipidus; this condition may be transient or permanent, depending on the species and the manner of performing the operation. There are cogent reasons for believing that certain hypothalamic nuclei with their fiber tracts must be considered together with the posterior lobe per se as constituting a functional unit. Since the hormones extractable from the posterior lobe are probably neurosecretions originating in the hypothalamus, it is apparent that posterior lobectomy may not completely and permanently eliminate these secretions from the system. See HYPOPHYSIS.

Anterior pituitary. The anterior pituitary produces at least six principles: five trophic hormones and a growth hormone. The trophic hormones directly control to some degree the functional capacity of another endocrine tissue. There are three gonadotrophins which regulate the endocrine secretion of the gonads; adrenocorticotrophin (ACTH), which conditions the secretion of adrenocortical steroids; and thyrotrophin (TSH), which influences the formation of thyroid hormone. While the growth hormone does promote growth, it exhibits a great variety of other metabolic effects. See HORMONE, ADENOHYPOPHYSEAL.

The three gonadotrophins are follicle-stimulating hormone (FSH), luteinizing hormone (LH), and luteotrophin (lactogenic hormone). The main action of FSH in the female is to promote growth of the ovarian follicle up to the point of ovulation; in the male it stimulates the seminiferous tubules and maintains production of sperms. LH cooperates with FSH during the final stages of follicular development, the two hormones promoting the secretion of estrogen and causing ovulation; then LH and luteotrophin stimulate the formation of luteal tissue and thus promote the secretion of progesterone. In the male LH stimulates the interstitial tissue of the testis and thereby increases the output of androgen. It is clear that FSH and LH have equally important roles in regulating both male and female sexual function. Both hormones are glycoproteins and have been prepared in highly purified form. See OVARY; TESTIS.

Luteotrophin. This hormone acts in the maintenance of the corpora lutea once they are formed. Perhaps the main action of this gonadotrophin in mammals is to initiate and maintain lactation by acting on the fully developed mammary gland. It stimulates the secretion of crop milk in pigeons and initiates broodiness in certain species. Luteotrophin is the first pituitary hormone to be isolated in pure form; it is a protein having a molecular weight of around 30,000. See LACTATION.

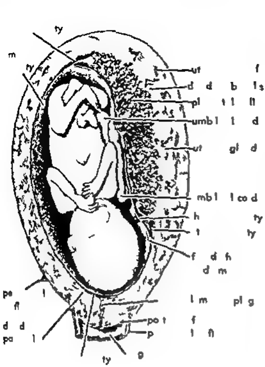
Chorionic gonadotrophins. These gonadotrophins, having anterior pituitarylike effects, are secreted by the placenta. Two such substances have been isolated; they are serum gonadotrophin (PMSG) of pregnant mares and chorionic gonadotrophin (HCG) of humans. PMSG elicits actions which are comparable to a mixture of pituitary gonadotrophin, but it has not been possible to separate it into fractions like those of the pituitary. The main action of HCG is on the corpus luteum or on the interstitial cells of the testis. While both PMSG and HCG are glycoproteins, they appear to be chemically different from FSH, LH, and luteotrophin. Gonadotrophins of placental origin are abundant in the blood and urine of pregnant women, the blood of pregnant mares, and in the urine of patients suffering from certain genital tumors.

Adrenocorticotrophin. When adrenocorticotrophin stimulates the adrenal cortex it accelerates the secretion of adrenal steroids. It restores to normal the atrophic cortices of hypophysectomized animals. ACTH preparations can be bioassayed on the basis of their ability to maintain the weight of adrenals of hypophysectomized rats or their capacity to cause depletion of ascorbic acid and cholesterol from the adrenals of hypophysectomized subjects. It should be stressed that ACTH peptides exert a great variety of extra-adrenal actions. There is increasing evidence that all the pituitary trophic hormones produce metabolic alterations by acting on tissues other than their target glands.

ACTH has been isolated as a protein with a molecular weight of around 20,000. Others find that ACTH activity resides in much smaller molecules (peptides) which are several times more potent by weight than the original protein ACTH. It is possible that in the gland the peptides are adsorbed on or combined with cellular protein. See ADRENAL GLAND.

Thyrotrophin. The normal structure and function of the thyroid gland in hypophysectomized animals is maintained by thyrotrophin. TSH is a small protein having a molecular weight of approximately 10,000; it has been obtained in highly active form but has not yet been purified. A dynamic balance appears to be established between the secretion of TSH by the pituitary and the titer of thyroid hormone in the blood, but other controls seem to exist also. See THYROID GLAND.

Growth hormone. Growth hormone is a simple protein having a molecular weight of about 4[illegible]



Fg 1 P g t h m t t 3½ m th pl s sag tt lly to h w th el t f th f t m mb d pl a t

Co d da h u q a la etal pr c troph ta n e k wn the g up wh h establ h pl nt l lat h p with th tt s e

l m t (reptiles bi d nd m mr l) th e tr mbry m mb a ut l ed pla e t t p l zati s f th ba e memb ne f d i all th p s p tes l f ct th b g nt g f pla e t t n port y d by o p a u l za d d n k the l g shell e d d y lk f d n gg a imply r ta d w tl th te t l h t h d H e pp r tly th nly pl t l f n t i e p t n h tl e e b m d fi at of the f tal memb a s nd only a d d p l nged hyp rs l ty f the t r n lt g

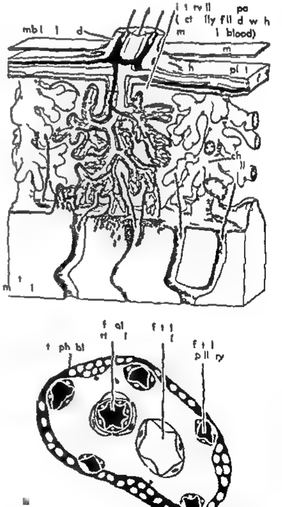
l s few l za d nd n ke a d ll ma np al nd e th an m mm l mpl te pl ntal f n f o u b e th egg e suppl d w th too l ttl y lk t p d th d f th embry fo i hm t t l b th In d q ate p o n f l min t a d st g f n t g n s w t o m t f th e m f l Th t nl m t th eml y te h ng p t rv g w th th rt th bl d b t they m t l ab so b ut m nt d s f w te t be et d by he k d y F ll pl nt t n n th f rm p ided b a t m l nd phy l gt al p al tt f th pr pal t mbry n m m b es th h r n y lk a nd llant Th m i n p b bly pl y a phy l g l l l

Physiological exchange Eff nt t ch nged p d l p x m ty f l g a a f fet l t s es t m t al bl od d t e t ry o ab p-

t e a e This s pr ided in mammal l y a rema kable reg l tory c operati n between th d el p ng uter layer (tr ph l la t) of the ch ri n t ether w tl th a ct lar yolk ac or allant b th and th m th r s uter ne li ing (end met ri m) In th typ cal mammal a placenta wh cl s always formed l y th h rion a d the allantoic

l the f t l nd mate nal blood tream are a cl e as a few th u andth of a mill meter fr m each th r (Fig 2a b) The s rface rea probably e al time l rger than tl body urface of the female In man th ratio i known to be about 8 1 N t o ly are th tw a lar ti ues clo ely appr ximated but ma y m mmal the arr nge m nt of th ve els is u h that in the area of i ter cha ge the tw blood tream flow i pp ite di ect n Th s c unterfl w pr ncipl greatly m c e th eff ci n y f interel ange

Pl enta a cla fi d i vari s way l ut the m t me n ngful i ba ed the de tit f tl lay e making up the ep n memb ne between



Fg 2 ( ) D g m of bl k mo d f m t f h m pl t (b) E l g m t f ut d of b ch ll

Pituitary gland disorders

Any pathology of the pituitary gland the master regulatory organ of the endocrine system Many hormones which directly influence tissue metabolism are elaborated by the pituitary but more important certain of these hormone exert a control on other endocrine or target glands such as the thyroid adrenals and gonad The pituitary is actually a double gland the anterior portion arising from an evagination of the roof of the mouth and the posterior lobe developing as a downgrowth of modified neural tissue from the hypothalamus The two lobes come together in a bony depression located behind the optic chiasma at the base of the brain *See* PITUITARY GLAND

The most common pituitary di orders can be grouped into two categories those in which symptoms result from mechanical changes in the gland and tho ■ in which hormonal imbalances are produced Hemorrhages tumor formation and inflammatory changes may cause symptoms by virtue of their direct effects Hormonal dysfunction although frequently caused by neoplasia may ari ■ in a grossly unaltered gland yet have pronounced ffects upon other ti sues *See* HORMONE TUMOR

The best known examples of anterior lobe dysfunction are the ca es of gigantism and dwarfism which result from either hyper or hyposecretion of growth hormones during childhood In adults hypersecretion of the growth hormone results in acromegaly marked by the appearance of enlarged jaws hands and feet and other change

Hypopituitarism indicates a decrea ed output of pituitary hormones and like hyper ecretion may in olve one or more or all of the endocrine secretions Cases of Simmonds disea ■ follow loss of all secretion and are characterized by a general wasting and secondary insufficiency of the ad enal thyroid and gonadal glands because of lack of tropic stimulation Adult women are affected twice a frequently as men and the clinical course may be rapid or may be prolonged over a pe iod of years depending upon the nature f the pathologic proce s causing the glandular deficiency

Deficiency of gonadotrop c hormones those which stimulate either the testes or ovaries may result in Froehlich s syndrome This is marked by excessive obesity of the female type f lu e of development of secondary sexual cha acte istics and sexual dysfunction In the ■ cases malfunction of other parts of the pituitary or hypothalamus is probably re ponsible for the obesity

The most important though uncommon d sease ■f the posterior pituitary is diabetes insip dus In these patients a deficiency of the antidiu etic hormone permits water to pa through the renal tubules without proper reabsorption As a result there is often a tremendous urinary output ome times as much as 20–30 quarts or mo ■ of urine a day

Most of the pituitary di order mentioned as well as tho ■ which are less common or c mplex in nature result from injury to or tumors of pituitary tissue Injury may follow trauma inflammati n, vascular damage or the development of cy t Frequently the cau ■ of hyper ecretion is the o er activity of a benign or malignant tumor both, however may be asymptomatic [E.C.S.T]

pK

The logarithm (to the ba e 10) of the reciprocal of the equilibrium constant for a specified reaction under specified conditions (for example of ent and temperature) pK values are often more con venient to tabulate and use than the equilibri m constants themselve The value of K for the di sociation of the HSO_4 ion in aqueous solution at 25 C is 0 0102 mole/liter The lo arithm r $0\ 008_6 - 2 = -1\ 991_4$ pK is therefore +1 991 The choice of algebraic sign althou h arbitrary results in positive values for most di ociation con stants applicable to aqueous solution The con cept of pK is especially valuable in the stud o solutions *See* EQUILIBRIUM CHEMICAL EQUILI BRIUM IONIC PH [T F Y]

Placentation

The intimate as ociation or fusion of a tis ue or o gan of the embryonic stage of an animal to it pa ent for physiological exchan e de igned to pr mote the growth and development of the youn enables the young retained within the body or ti sue of the mother to respire acquire nour ment and eliminate wastes by bringing their blo treams into close association but ne ■ into d rect connection (Fig 1) Placentation characte izes the early development of all mammal exce the egg laying duckbill platypus and piny a eater It occurs in some species of all other orde of vertebrates except the birds In fact in certa sharks and reptiles it is almo t as well devel p as in mammals A few examples are al o kn among inverteb ates (*Peripatus* certai i tunicat and inse ts)

Placental modifications With few excepti the fetal st uctures used to establish placental lationships w th the mother are modifications organs present in kindred egg layin (oviparou species In the fishes sharks and rays and a phibians the ■ include g ll filaments the tail the per cardium and the primiti ■ yolk sac (mid and adj cent entral body wall) The e ential p ental mod fic tions of all these are increa ed face a ea and as ular ty and intimate contact a highly asculari ed and often secretory area the mother In fi hes this latter is usually vary in sharks and rays the uterus ■ amph ians the ut u the skin Skin ge tation unique t cert in ov pa ous South American fro A the eggs a ■ xtruded they are fertil zed by mal nd pl ■ d on the b ck as in *Pipa* r in a po h on the back as in *Notot ema* Here they come embedded in highly vasc lar compartme and rece e both oxygen and n uri hment fr m m ther lood st eam ■ beary

nt pa t of the body Typically the shi ld c er th head epar t nd r o bl upo the ody arm by p ed b ll and k t a t lat n he lde t kn wn plac derm ar of Late S lur an g D r ng th De n tle a he ed a d mi a c o e all ther co t mp aneou g o ps of a kb n d n mals Their succ s how ve wa h rt li ed and by the l s of the Dev nian except f r C tosel h from Mi s pp an ro ks d B lg m) th fi hes b c m t ct See ICA HODII

Th plac d m separ ble into two m jor l i i n the Arthr d ra nd Antiarchi W th n a w d ly d played ange of h pe s ze and an t mi e l riat both g up p s e ed few omm n th r et ri t The r r n m f rm d chi fly of ca t lage wa to t r etu compo ed f a h m th n d l pa t pp t ng la g lfact y orga mod t si d a d forwa d t ted b tal nd n tat n and relati ely l ng obu t t o c pt l t on Var o d mal bo es f omer ne nd p r ph idal n tur ften n tted the entral rlac of the b a a e with the fo m r metimes mod fi d a ntegr l part of th b t g mech ms f the upper jaw D sally a d lat ally a d smal h eld mpo ed f g l r of med an un p r d nd p i d l t al plat f b n p ot cted th n u ocr n m i al keleton and b an h l hamb The c al sk let n p zh p thro gh p i n e of p am t lt c rt lag n s co di t n d c qu t fa l r t be pr erved tr th f tl t te rema mo t mpl t l unde tord If wev part al d h d al s fic t o s F r ev d n e f th mand b l a h ma y rtl od e The p d fi ti ns e l ted n the qu d t a e f th upp j w d the arti l a d ymphyse l r g n f th l we E ch f th p m ry uppe a d l wer j w el ments pp t d gl par f opp g b n Adapted f r eth h ng o i lik h r ng a t o th e l m t wer n t d e d s b t t n ed t g w l nla g d r g the l f f th nd d l ft n d playi g namel d d nt l s and e l m f d t al) k r e P t a d ug t s th m s of t qu d ate and t l r o fi t f the ja g t h me t s ttach m t p b bly w th m d fi d el me t f the er d l r h Th f t l a t om f th pl d m mph tyl t pe f j w a te la t n w th th b n m y b t lated with a u pe f y m d b la d e t r t f by d n g ll l lt t d l p ra ul p rt S A TI R H AR TRO IR

Th th a m a th t f the ephali h eld mp ed f med a p d a d p d late l l m nt Thes d m l l a n t d b l th l pp ng t d t ghtly t l k g d t t Th b kl m t mp bl n p i n d f t t th k l r l h uld r g dl f m d d b y f h d d st l y tly d ff t d l pm nt i h f th d pl d m tock Am g llee l est w lla th l gl d rvai l t f m a t n u

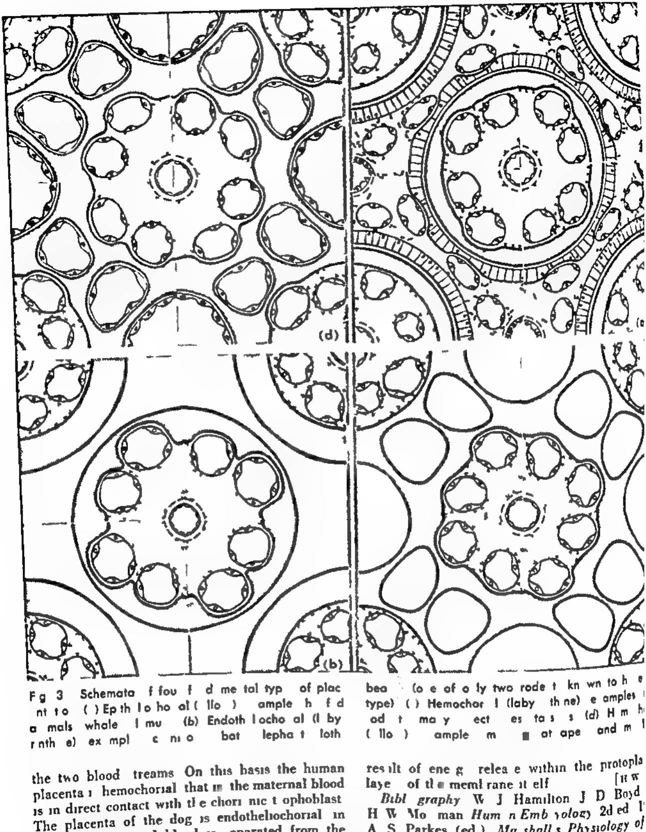
sh eld over the back de and enter of the tru k In the later yo ng r f ms it may be ome vari u ly m d fi l nd red ced olte w th complet l es f c nnection betw en the l r al and entral part and ven of th t pi al m l il arti ulat n w t l th h ad armor Th body an l tail beh nd tl e tr nk rm r s generally fi hl ke and may l e e tl er scaled or n ked The internal axial skel t n l known adequately in only a few form I the arth od e C r steus the not cl rd was per i tent a d extended t th t p f the het r cercal audal fin In addition segmental conden t ns of b nv t u r eal dors l eur l and ventr l hemal a cual a One r two medi n d r al fin we e pre e t supported nt rn lly by r ys The hyp ch d l l b of the caudal fin s pre umed to be small Of paired fin p e t r ls and pel cs were ge erally pre nt. The pect ral appendag s w r of variabl fo m A pai of fixed or mo able spine may al o proje t fr m th s des of tl e thora i arm r in the pos ti n f th se fins In arthrodi the fixed pi es became pr g e i ly reduc d tl rough ge logi time and tl e fun t on w s g dually replaced l y p port nately larger a d larger rm l fin with tern l rays rticulat ng on a primary ca til g n u ho ld r girdle ugly a ciated w th the dermal tr nk a mor

The Placoderm f m an e tr o din ry gro ip of fi h s who remarkably di r e adaptation t life n b th fre h nd mari wat rs mak any pl yl tic nt rpr tations diffi ult I the p e nt t t of kn wl dg th y c o ly be egard d s n early ab r ant mblag of armo d backb ed a imal wh re embla ces to ac nth dian ho dri hthy s n and ea ly o te hthy n fi hes we a her tage f om a n mmon ea ly Pal z n ancest al st ck f jaw d e t b te S e PALAEO PONDYLOIDEA STEGOSELACHII [D H D]

Plague

An i fe t o d ea e of man and odents ex t ng a pneum ni d b b ic plag e and a ed l y th ba ll s P st ella pest s I wild r d ts th d e s i kn wn as yl t pl gu Plag s t n m tt d f om de t to ode t a d f om le t t man by the fl a (X psyll h p s) The d s h been known the th d tury f r t p nd m s d epid m cs u h a the Bla k D th n 1630 (M l n) in 166 (L don) and n 1721 (M r lles) Al xander Y n d sco r d th c of th d ease n 1894 d ng a w rld wide uth ak n the 1890

In th n mal b dy the b llus i g am nega t n nmot l and a sh rt d c o d r a la g d fety p n h p It r s rrou ded by a lime l y o n el t Thi a r bi o g n m gr ws well but l wly o med m t i g y t n d blood at 37 C th t me r qu ed f ll d i n be g b ut 4 h u Glu o e, g la t e f uct e b t n t la t e r f rm ted w th ut p od t f g Th l l ty to f m nt gly r l s h acte i t c f t i va et e of P t nd is n a d n d t m ng the p



Fg 3 Schemata f fou f d me tal typ of plac nt t o ( ) Ep th l o ho al (llo) ample h f d a mals whale l mu (b) Endoth l ocho al (l by r nth e) ex mpl c ni o bat lepha t loth bea (o e of o ly two rode t kn wn to h e type) ( ) Hemochor l (laby th ne) e amples od t ma y ect es ta s s (d) H m h (llo) ample m at ape and m l

the two blood treams On this basis the human placenta i hemochorial that is the maternal blood is in direct contact with the chori nic t ophoblast The placenta of the dog is endotheliochorial in which the maternal blood is eparated from the chorion by the maternal capillary endothelium Other conditions are epitheliochorial synde m chorial hemoendothelial and endothelioe dothelial

The phy iology of interchange through the pla cental membrane is a fertile field in pre e t day re earch Although imple physical diffi i n and osmosis are factors it is now known that probab ly of greater importance are acti e membrane tran port mechani m Thi tran port through the pla cental eparation membrane is work done as the res ilt of ene g relea e within the protopla laye of the meml rane it elf [H W

Bibl graphy W J Hamilton J D Boyd H W Mo man *Hum n Emb yology* 2d ed 1 A S Parkes (ed) *Ma shall s Physiology of prod ction* vol 2 3d ed 1952

Placodermi

A la ge and ar d a emblage f Pale z ic fi u ually cate rized a a z l gical cla appeared nly l ghtly late th an the Acanth The Pl c dermi c n t t ite the ec nd olde t g of p imiti e j wed tel rate a imal A im l y their name wh i h m an p l te kinned placod rm are ch racter d l the le el p of a complex b ny armo th e b

Distribution and varieties S mewhat m r th n o e th rd of the ea th s la d are o c p ed by pl W th th pti n of s e-l athed Ant arct a a h c t te t n t la t on maj r xpan e f mooth l d n addi t to n me us small r area The h ef pl in f No th Am ric So th Ame a nd Eu a a l e t th cont n nt l t w th ext n i ns r achi to the Atl nti Th mo t xte pla f Afr ca cupy mu h f th S ha d e h uth nto th Con B n Mo h f A tral s m th w th ly the e tern margi la k ng pl s t r a n S e TE RRAIN A EAS WO LD-WIDE

f th t pp o h t flat es while not r o t tute m r po t n f th wo ld pl i M t mm nly they c l n l w ly t l m rg th l ct f maj e s t m S m cup th ll r f inl d b wh t n i tr am d po t n h s ccu ed The m jor ty f pl in h a d t n tly reg l n e fa f m a a lt f alley ut t ng by tr ms or f egul r osio and depo t by o t ne t l gl c

Pl a m t m des g t i by tl e t t n n whi h they r In mmon pe ch t l pl n t ny tr p f m oth la d dj e t t th ho l th ugh geol gy th t m ss oli n r tr ted t h pl n th t wa f m rly p t of th h ll w a bott m An xample th So th Atl t a d G lf m rg n f the U t d t t (e C ASTAL L D OR IS COA TAL L I) Int rm t e pl s l b tw n m u t n r ge a d ba pl n a e s d d b h h nd gh l d Upl nd pl n (metim lo ly t rm d plate) I t h gh le to r t l t w ll abo e eighbor u f e wh l l wla d pl a e th ly g e a l l d t tly b l w dj ce t la d

Pl r lso m t me l fi d d g t the p that h e p d ed the i t t e f e f at Th di e e d d b l w

Origin Th t t f pl t rang lly t d t l y that r d m a e f th ro l d d p t l p s r th fo c th t de- f rm th r t t ll The m t xt a f pl s h th f t r o N th Am r th t f rthw t E r g n ally p t h h h xp r d thi g m r r tha l w h d p g f th r t e l p r d f geol g al hi t Th gho t th t t me th gr l i l f e h b abl t m i l a lat ly bdued u fa Cert tl l d g tl upl d pl i f r l d so the t l Af a d r B l h f fe ed m d at g al pl fti l t g l g t m b t h t t b m bject d t d ep all y c t t g

M n pl l l se vte t h w h b f rmed m r wh t l d f mati n ll been t M t f tl r pr t d p sed sect f th t t wh h ha b p t lly fill l l mooth l d d po t f d br rr d

n by tr ms f m the urrounding mountain Ex ample f ch pla ns a e the Central V lley f Cal f rn a th P Pla n of n rtl e n It ly the pl in of Hungary he Me op tam an plain the Tarim B n f c ntr l A a and the Indo-Cangetic pla n f n rth rn Ind a and Paki t n

REGIONAL SURFACE CHARACTER

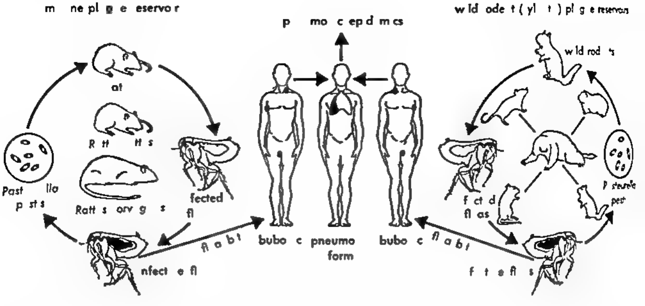
The urface f atures f pl in re ult ma nl f om loc l r onal nd dep itional acti ty in rela t ely r t g l g t me Each of th maj r gr d t n l ag nts—run i g wat r gl al ice nd the wind—p odu s t own character tic et f f at r d ny g ve ect on f plain terrain i h ra te d p ed min ntly by feature typ cal f pa ti ula ag nt

Features associated with stream erosion Val leys a d the di id betwe n them har cter ze plain culpt red largel by t eam er i n Sur fa a e usually ir egular rath r than flat l ut dif fer among th m el n in in form ar ange- m nt and pac ng of the valleys. Sinc tream e d d plains are far m re wide pread than any ther cla th s l fferenc are pec ally ig ifi a t nd f eq ently n unte d

The l pth w dth and cr ssecti f rm of tr am all ys dep d upon the r latı e rat s of o i nal deep ni g f the vall y by the tr am t lf nd of e on l wid s f the ll y by the c tt ng of t b tary ne a d by a n wa h and slow d wnw rd reep f o l n the valley s de l ally a d d by u d s tt ng f the lope ba e by th t eam N a r w t ep-s d d alley re f o ed by t ep s ft fl w ng str ams that r d p dly a d by an ab e ce f xcess s urfa e un ff d wn th ll y s d f om the ad ja t pl nd Con r ely br d gentl d d ll v a e typic lly a so iat d w th l w fl w i g tr a s f ge tle g ad ent alley walls are om pos d f we k materi ls a d are h a ly wa h d by un ff Si s str m fl w g o pl s a u lly gentl s g ad ent, ll ys s plan a ommo ly w d h ll w and gentl slop d but g ifi a t ex pti ns n m r u

The sp ng of all y n pla n nd ates the ta to h h d l pme t of the t am y t m h ad a ced N rmally th gh the o se of time m jo t am de l p an nc e g num be a d le gth of tr buta i u t l nt ally the e t d an ge ba i i ce pi d by alley nd th de l pe When th po t is a hed tr butary s wtl mpl t Cont ued develop ment n ol th r du ti n of l p nd l we g f d des betwe n t m nt l the wh le f c l b en b ught l w

Pla n d ff r gr atly in th t g f devel pm nt th r st am t m ha r ch d Pl i wh h t l tary th h ghly mpl te tl t br d n t pl nd ma n b tw w d ly pa d all y lled y thf l Pla n h h t b t ty gr th i mpl t a t m l m t a d r t p lly oll ng rf s l ke the App l h a l dm t l tween W sh ngt D C



Ep dem ology of plag e (G rg W ll ams Hooper Fo dat U ty of Cal fo a)

demiology of an outbreak of the di ea e *P pestis* fails to hydrolyze urea Under favorable laboratory conditions it remains viable for months even years in rat flea pellet for months It i inactivated at 55 C by 0 5% olution of phenol in 15 min and by treptomycin and tetracycline Of its at least 10 antigen the envelope antigen and the powerful toxic antigen are significant in immunity and pathogene is

Plague may be diagno ed by culture of blood or tissue fluid obtained from lymph nodes of man or dead rodents or by animal inoculation Cultures may be quickly identified by a specific bacteriophage or more readily by agglutination test with potent antiserum After the diagno tic material is rubbed on the fre hly haved abdomen of guinea pigs they die in 2–6 days bacilli can be found in blood and spleen films

In warm climate plague usually is bubonic so called becau e of the characteri tic swollen lymph node or buboe Bubonic plague is usually transmitted to man by rat fleas It may pread rapidly at times among commensal rats and mice mainly through the rat flea During rat epizootics the e fleas carry the plague bacillus in the midgut and pro entriculus from which it is regurgitated during the bite In cold climate it is more likely to take the much more fatal and contagious pneumonic or ton illar form Pneumonic plague preads from patients with primary pneumonic plag ie or fr m patients with bubonic plague and econdary pneumonic infection

Endemic (sylvatic) plag e may be maintained by any of 3/2 burrowing hibernati g rodent such as field mice quirrel pra rie d g v od rat jermophile or marmot which are widely di tributed in the we tern third of the United State in large area of South America in Centr l and South Africa in Iranian Tu ki tan and Central A ia

Human infection i rare in the United State and ari e from exp ure to wild rodent or their flea Plague is often a terrible health problem in citie in India Burma and Indone ia although it i presently in a decline It till per i t there however in the wild rodent

After treatment with sulfonamides (particularly ulfadiazine) treptomycin tetracycline or chloramphenicol pectacular effect ha e been observed e en in pneumonic plague which wa formerly irremediable

Perpetual y tematic warfare a ain t rodent is fundamental to prevention The potent rodenticide Warfarin (dicoumarin) i u ed to free citie of rat and to establish rodent free belt around towns and village In the control of epidemics the fir t con ideration mu t be elimination of the flea by u e of in ecticides with re idual act n (DDT in 5% kaolin or malathion) *See* ACCLUTINATION REACTION BACTERIOLOGY MEDICAL BACTERIOPHAGE BRUCELLACEAE [K F ME]

Biblio raphy R Pollitzer *Pla ue* WHO Mono graph 22 1954

Plains

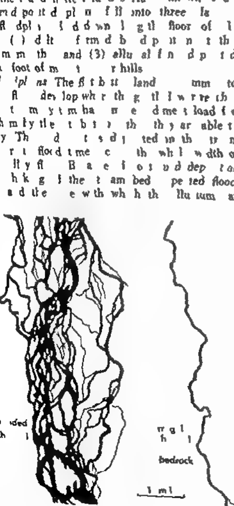
The elatively mooth ections of the continental urface oc upied l rgely by gentle rather than teep l pe and e hibiting only mall local differen es in elevation Becau e of their moothness plain land if other condition are fa orable are e peci lly amenable to agricultural u e The absence of exten ive teep loped feature of great height n t only dec ea e the number of ol ta les t h man transp rtat n or in pa t time t the mig ati n of animal but al perm t the free m vement of ai m e a fact of great meteorolog cal importance It i thu n t urpri ing that the majo ity of the worl l maj r agricultural re g lo ely m hed tran p rtation net ork an l c ntration of p p lation are f und n plai N r i it unexpect l that exten i e plain are are w thin wl ch climatic con liti n ary but lightly ov l l ta

ft n d appea i g into th g ou d after a sh t fac run E e t ally olut avte nea th rf ollap e f rm g urfi ial dep e ns of iz S me re h llow nd i n j cu us the s great t p walled pits r elong t d l d all y S me f th m li dep n c n tan lak he e th tlet a e pl gged with lay Th m t t n v a ea l oluti n featu ed pla n i th Un t d States ar ce tral a d n rthe Fl da d in th Pa handle of T xa In b th f th a a h llow ink h l s me i ke filled r num o S me f th rea of m t t e l t w k have de el ped u fac fa too r gh t f ll der the b d ng f pla Th pec ally t u f r the m unt i u a es f gr at k and luti n valleys i the Dalma t h t f Yu o l a S KARST TOPOGRAPHY

Patterns associated with stream deposition

Allu l f t r a so alled f om th t rm l l i m h h efe t y t e m d po ited mat l A a g p allu i l pl n a e m n the moothe t a d fl tte t la d s rfa kn wn T u t e m d po it d pl n f ll into three ls (1) fl dpl i l d d wn l g tl floor of l l y ( ) d lt f rm d b d p u n t th tr m m th and (3) allu al f n d p t d t th foot of m t r hills

Fl ipl ns The fl t b tt land mm to ll fl dev lop wh r th g tl l w r re th f t m y t m ha n e d me t load f d t th m l y tl e t b t i th th y ar able t c y Th d t s d j ted in th tr m b d r t flo d t me c th wh l w dth of the ll y fl B a e f o t u d dep t on nd h k g l the t am bed pe ted flood ng a d tl e e w th wh h th llu ium an



F g 3 Ch p tte f t m b n l lluv l d bed o k rf (F m V C F G T T w h A H R b d E H H mm d El me f Ge g phy 4th d M G w-Hill 1957)

b m ved tream continu lly l ift the r channel n fl odplain On plains f fi e silt the cl an el u ually l ghl s nu or m andering while n a ndy floodpla n the cl annel is brai led that l r ad l allow and intricately s l di ided l y nnum ral l and l ar In either ca e many l op or t and of aband n d chann l n w m tly dry and filled in e tl e flo dplain surface On ilty fl dplains the highe t la d s comm nly foun l m med ately dj cent to the ha i el while fa th r li ck fr m the tre m th urfac is lightly lower Th hi h r tr p called natu al le ees are l ed by cti deposit on du ing fl od wl en th l c ty of flow s abruptly he ked and the bulk f th s dime t dr pp d imme li tely as the w t r l ave the w ft c r ent of tl e de p chann l t p ad thinly r the pl in

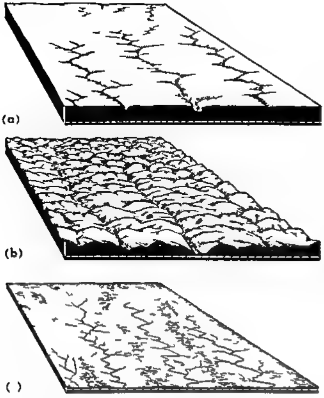
On m jor fl dpl i s the ground ater tal le i ev ywhe e clo e to th fac and sw mpy land s c mmon th ba d n d h nnel and hallow wales b l nd the nat r l l e F r tl i rea n the n t ral levees are pe ially so ight aft r for c lti t on town ite and tran p rt t n ute They no mally j r de the b t dra d l d n the fl dpl n and the la t to b flooded as the water

Tho gh ha a e l by a high wate table and ec r ent fl d fl odpla s e pec ally lty one e ft n pr zed ag icultu al l nd be ause f th f l e s ly t ll d surfa e In om ca e tl e al l m i al o mo f rt le than the l of th su r nd pland

He e nd there along th d s of alley b tt ms and me h t b e tl p e ent le el of tre m fl oupla t ps of mooth land t d in the f m f b n he r t r aces made p f lluv um Th se remn nt f e tli r floodpla n that h e l en largely d st y d by a e al of d w utting by the r str am In many in t the t e m h s th n ec mm n d d po ti n a d ha bu lt a ew fl odpla n t l w level The e l lu al te r a often aluabl agr c ltu al l nd d al re w ll f r t wn te a d t n porta ti n ut s bec u th y tand abc e flood le ls

Th u fa e f ture of deltas a e y the m a th ju t de rib d In leed delt oft n mply th wa d ions f fl odpla n A r le h we r th d lta fa e e en le w ll d a ned th n th floodpl u f e and at it uter m g may me g with th ea thr ugh bro d belt l m hy land A the delta gr w t n l l g ng f the tre mouth p odu e pe ted d v on and b fu ati f the ch nnel Hen n a well de l p d d lt d ha g i rar ly thr ugh a ngle h nel l ut th ugh a p e d n t k f d ve g ng l nels d t ib ta es

Delta The e v ry gr tly z nd form Many l ke th e of th M s ipp th N l the D b the Volga a e mm n fan haped f at r that h e p due d b oad ast l b l by th gr wt Othe s l k th se f th Col rad th P th T gr Euph ate th gh n le s t n i a l ppa ent tl map b cau e th y h b n b lt l g oa t l mbayme t



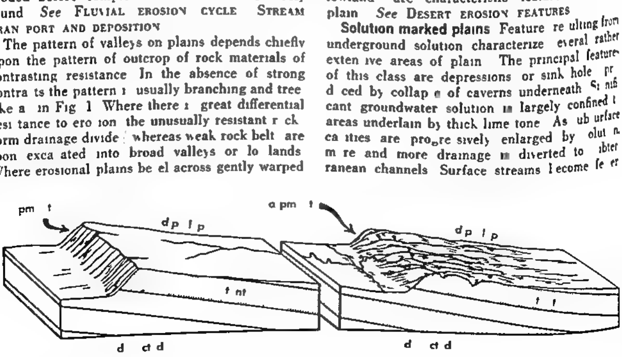
Fg 1 Ide l stages ı th sequence of d elopme t of a la d s f ce u der the effects of t m ero o (a) Youth (b) matur ty (c) old age (From V C F h T T ewarth A H Rob so a d E H H mmo d Elem t of G graphy 4th d McG aw H ll 1957)

and Atlanta Georgia Old age plains (al o called peneplains) hould ideally be low lying and smooth since they would repre ent the ultimate of erosion However they require so long to de velop that they are u ually re uplifted and re eroded before completion and hence are rarely found See FLUVIAL EROSION CYCLE STREAM TRAN PORT AND DEPOSITION

The pattern of valleys on plains depends chiefly upon the pattern of outcrop of rock materials of contrasting resistance In the absence of strong contra ts the pattern ı usually branching and tree like a in Fig 1 Where there ı great differential resi tance to ero ion the unusually resistant r ck form drainage divide whereas weak rock belt are soon exca ated into broad valleys or lo lands Where erosional plains be el across gently warped rock strata of varying resi tance the belts of out crop of the more resi tant trata form trips of higher rougher country with an abrupt escarp ment on one margin and a more gradual dip lope in the direction toward which the trata are in clined The e cue tas are common features in th American Middle We t and Gulf Coa tal Plain and in western Europe The various wold and down of England and the cotes of northea tern France are cuesta ridges

Mo t plains that develop in dry climates are characterized predominantly by tream produced landforms in pite of infrequent rain The devel p ment of valley sy tems and ero ional feature f l lows the ame general rules as it doe in hu id regions However some differences in relati e rates and relati e significance of certain of the devel p mental proces es produce di tinctive land cape characteristics in arid land Fir t, rock decompo i tion is very slow so that the surface accumula tion of weathered material ı normally thin and coar e textured Second the par e vegetation af fords to the naked surface little protection aga st the battering and washing of the occa ional t r rential rain As a re ult the upper lopes become trongly gullied and often stripped of much of their covering material leaving bedrock exposed over wide areas The debris that ı eroded from the upper slopes is rarely carried far ho e er becau e of the hort duration and local nature of the rains and hence the intermittent character of tream flow Therefore most of the debri load t dropped in the neighboring ba ins and valley floors drowning broad areas beneath plain of silt and or gravel Hence denuded and gull ed upper lope and broad depositional flat in the lowland are characteristic features of desert plain See DESERT EROSION FEATURES

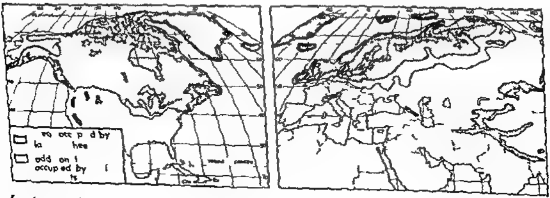
Solution marked plains Feature re ulting from underground solution characterize everal rather exten ive areas of plain The principal features of this class are depressions or sink hole pr d ced by collap e of caverns underneath Si nifi cant groundwater solution is largely confined t areas underlain by thick lime tone As ub urface ca ities are progre sively enlarged by olut n m re and more drainage is diverted to ubter ranean channels Surface streams become fe er



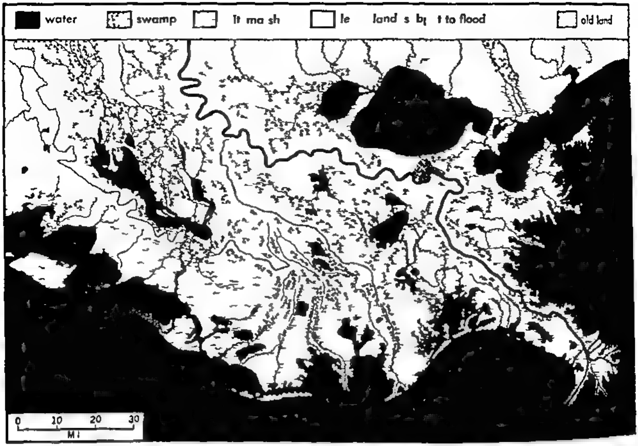
Fg 2 The str ct e a d rfa e fo m of c est D cted fo m how at ght espe lly mmo (F m V C F h T T warth A H Rob s a d E H Hamm d El m t f og phy 4th ed McG w H ll 1957)

Fg 5 All 1 f 1 g t f m n p dm f
lluv I pl n l d p d C l f (Sp A
Ph t)

b am e p ed Th I we y a ts f form r lak
fl a d th t r marg n f tal pla s e
fte p u ly p ly d a d
Th fl t u f p wl h D tr t Toled
Chi nd W n p g t nd all la t ne
pla (Fig 7) e the f m d B n lle Salt
Flat (t Ut h Th th Atl t d
Gulf m g s f th Un t d St te d m h f th
Ar t (f N b r a pl f newly
m g d tal pl om of th pl ep e
t slu bl ag ltu l land other a e t s
ly w mp o ndy 5 DELTA FLOOD PL I S
Character from recent glaciation Pl m
tl gl ted d tnct e s ct t s of
f rm a acc rdan e with th o respond ng va
et of r o al and depo it I p ce l ed
A a gr up pla n owing the r f ce featur s
la g ly t th w k of co ti ental ce heet are
d ti gu h d by th ab e e of sy t m t c inte-
g t d p ttern f t am alley and d l e by
th p e n e f g e t n mbers f l k s d
s amps a d by th e e ce of t f m te-
r l b sl not d d fr m th l al bed ock
Alth gh th e we e p bably f major pe iods
f glac l gr th nd decay d r ng th I Ages
ly th se a a d d ing th la t gla tal
t g (th W s n gl c ati n) how d tinct vely
e p da d u face f ms Th fo ms produc d



Fg 6 M p sh w g d by f m ne l gl (All R F Fl f f m V C F h G T T w th A H R b d E H H mm nd El m t f G g phy 4th ed M G w-H ll 1957)



Fg 4 Swamp marsh a d at l le ee la ds n the M ss s pp R ver d lta (F m V C F ch T T e-wartha A H Rob n n a d E H Hamm d El h of Ge g aphy 4th ed McG w-H ll 1957)

Some great rivers have no true deltas because their ediment load has been dropped in ome interior settling basin as the Great Lakes remove most of the sediment from the St Lawrence sy tem and the Congo depo its mo t of its load in its broad upland basin

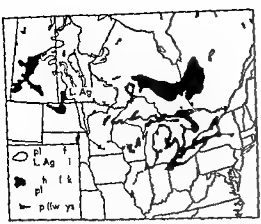
Like floodplain delta are sometimes highly valued as agricultural lands though they ha e the same problem of poor drainage and frequent flooding The Nile delta and the huge silty delta plain of the Hwang Ho in north China are famous centers of cultivation Many deltas of which that of the Mi si ippi is a good example are too swampy to permit tillage except along the natural le ees The Netherlands occupying the combined deltas of the Rhine and Maa stand a an ex ample of what can be done toward reclamation of such lands when the need i great

If a tream emer s upon a gentle plain from a teeply plunging mountain canyon it velocity is abruptly checked and it depo it mo t of its load at the mouth of the canyon Be au e of the tend ency toward repeated choking and diver ion of the channel the depo it a ume the form of a broad preading fan e s tially im lar to a delta even to the di erging d tril utary chann ls U ually howe er the gradient de eloped are teeper than tho e on a delta e pecially near the head of the fan where the coar e t ediment i to be found

Alluvial fans Small indi idi al alluvial fans are common feature in mountainou cou try e pe cially where the climate i dry e cept for occa sional torrential showers Particularly ignificant however are the occurrence alon the foot of long precipitous mountain fronts of ro of al luvial fans that have coale ced to form an e t i e gently sloping piedmont alluvial plain Such surface sometime achieve great areal extent The city of Los Angeles is built on uch a plain Still larger ones occupy much of the outhern part f the Central Valley of California and tretch ea wa d from the Andes in north e tern Argent na Paraguay and eastern Bolivia

Becau e of their moothne s and e of tilla e allu ial fans like other alluvial surface are often e p cially amen ble to c lti ation They are par ti ularly ignifi ant in drier a ea partly because of the ea e w th which water may l e conducted b grav ty f om the mountain canyon to any part of the fan and pa tly because the thick porou al luvium it elf er e as a re ervo r in v l ich ground water i nat irally tored

Cl ely ll ed to tream depo ited plain are la s trine r lake l ttom plain and new ly emerged coa tal plain which are recently exp ed area of tl e former hall w ea l ott m The e are the nearly featureles urface f ed mentary dep t tl at ha e l e n carried int the b h f water b tream r l y wa e er i n nd f rther moothed by acti n of wa and c rrent Fo mer beach li s a l oth r h re featu e ometin e in m lt ple et often f rm tl e only noteworthy l eak in the m n t n i flatne In me pla e hallo valley l ave be n cit l y tr m ce the e



Fg 7 Th pl f f m L k Ag d th gl l f k pl N rth Am a (F m V C F h T T w rth A H R b d E H H mm d El m t f G g phy 4th ed M G w H ll 1957)

Patterns reflecting wind action Fe t re f rm d bv th d are l w de pr ad and a r le l obt e th th f m p od ced by r m d glac S th wi d n tt ck ly whe th f c i almo t fre of g tat t w k t t gly d t nly i id r g ons d the n ty f b h a d c nally e p ed r e bed n mo h m d l d T d y pl d field e al imp rta t pr y f w d e t

Th m t t ki g and gnifi a t w d p odu d f at es a e a d d e Whe a d xp ed t t g i d t i m d abo t f ho t d ta d umul t n h th g al v c n t f it pla f g S d d e a m ma y form f m r g l m nd a d elo g ted dge t e t h p d hill nd a o s a a g m t f d wa d p nd g p tly upo th pply f a d th at r f th u d ly g u f c d th t e gth d d t n l p r i t e f th w d ly all th t ly ext a f d d e f nd th E t n H m phe pe lly th S h a A bi tr l A d th t f Au t li M t l th d h b f ipp d p f m allu m th t ha b d p t d d n b nd l l d

l e l r g n f th w ld ot bly n n th t l N l k d th nt l nd we t n S d o th f th S h r te f d h lec m d by g t t a d fi d po t th y we f m d gg t g the po i il ty f l m t b g

Oth wi d f m d f t es r pol hed nd t hed ut p f b d ock th t l w the ff t f n t l d ff t ng gr l p em t lt g f m th w w g t f fi m t al f m m ed allu um d h ll w bl o t wh h a d p f m l by l c l d e

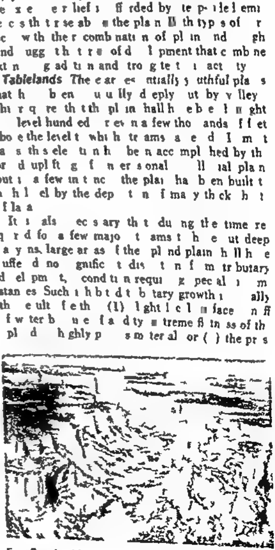
Th f lty m t l m d by th w d s r d ma tl b d pa f co nt y d wn l f m th pla f r g Th ugl lly th n th mantle n places reacl es a thi kne s of a f w t s of feet thu mewhat m difying the f m of th u fa e The extens depo its of un tr t fied b ff c lo ed lime-ri h ltv mater al k own s l e a e belie ed t have orig nated fr m su l w nd laid depo its Loes is bundant in th cent al Un ted States a tern Eur pe and uthe n R s a nd m i t r r no th China It yields r d ily t gully ng e os on and ha the facility of ma n ta n ng ema kably steep lope so that ero i nal terr d loped n deep lo is ften u us ally r ugh a d a g la *S e* LOESS

INTERRUPTED PLAINS

Inter upted pla ns or plains b oken by om feature of n i lerable r l ef o cur widely nd me it ind pendent treatment Tl ey m y b d d d nto tw co t a t ng gr ups (1) t bleland whi h ar pla d pl ns deeply ut at intervals by steep-s d d alley or b oke by escarpments a d (2) pla s with pac d h ll r mounta n in which the x e e r lief i ff rded by te p i le l emi ne c s th t r se ab the pla n B th typ s of r fac w th the r comb nati n of pl in nd gh l nd ugg t h t r e of d l pment that c mb ne xt n g ad ti n and tro g te t i act ty

Tablelands The e ar es ntially y uthful pla s that h b en u u lly d eply ut by v lley Thi r q re th t th pl in hall h e b e l n ght t level hund ed r ev n a few tho ands f f et abo e the level t whi h tr ams a e d l m t a s th s ele ti n h be n acc mpl hed by th br d upl ft g f n er s onal ll ial pla n but i a few in t nc the plai ha b en built t h h l el by the dep t n f ma y th ck h t f la a

It i als ec s ary th t du ng the time re q r d fo a few majo t ams t h e ut deep a y ns large ar as f the pl nd plain h ll h e uffe d no gnific t dis t n f m tr butary d el pm t, cond ti n requi g pec al i m stan es Such i h b t d t b tary growth i ally th e ult f e th (1) l ght l c l face n ff f w ter b u e f a d ty treme fi tn ss of th pl d h ghly p s m ter al or ( ) the pr s



Fg 8 A id f t bl l d C y d Ch lly N t l M m t th t A (Sp A Ph t

elsewhere by earlier glaciations have been largely obliterated by stream erosion and soil creep The last glaciation at its maximum covered all of Canada the Great Lakes states and New England as well as Scandinavia Finland most of the British Isles Baltic Europe northern Russia and northwestern Siberia These are the areas of glacial plains

Northern and eastern Canada and the Fennoscandian upland the areas in which the ice sheets developed and from which they spread out now exhibit more evidence of glacial erosion than of glacial deposition Over broad areas the soil has been largely stripped off exposing patches and knobs of scoured bedrock Shallow depressions have been eroded in the underlying rock and patchy deposits of glacially transported debris (drift) are strewn thinly about over the surface Lakes and swamps of irregular shape are extremely abundant Some occupy the eroded hollows others accumulating where streams have been blocked by drift deposits Streams wander from lake to lake with many waterfalls and rapids along their devious courses

These areas of dominant glacial erosion owe their existence to two factors First the unusually resistant rock that happens to underlie both areas did not yield large quantities of drift Second most of the drift that was eroded from these regions was carried out toward the outer edges of the ice sheets where melting permitted it to be dropped *See* EROSION GLACIATED TERRANE

Because of their patchy thin and stony soils and large areas of standing water the glacially scoured regions would not be favorable areas for human occupancy even if the climate were less severe than it is Even the coniferous forests native to the areas are neither dense nor luxuriant

The outer parts of the glaciated areas on the other hand are characterized chiefly by features of glacial deposition though erosional features are not rare Throughout these areas in western Canada the north central United States and northern Europe outside of the Fennoscandian upland glacial drift was strewn over the preexisting terrain in a sheet of irregular thickness and varied composition

Till Much of the drift represents mixed rock and soil material deposited beneath the ice or at the edge of the sheet directly by melting ice This material called till is as a rule most thickly deposited in the valleys and thinly over the ridge tops thus having the effect of reducing terrain irregularity The surface of the till sheet itself is usually gently rolling with many shallow depressions containing lakes or swamps numerous haphazardly placed swells and hillocks and no systematically arranged stream valleys Hummocky often stony ridges called marginal moraines mark places where the fluctuating edge of the ice remained stationary for long periods of time In several localities notably in eastern Wisconsin and western New York are swarms of smooth low drift hills all elongated in the direction of ice movement The mode of origin of these drumlins is uncertain.

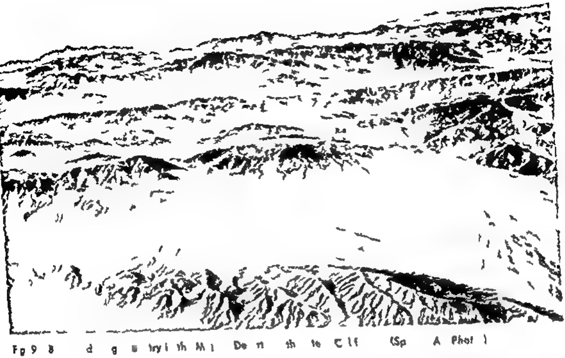
The surfaces of stony till plains are usually more irregular than those on clay till Northeastern Illinois has a remarkably smooth surface developed on clay till apparently eroded from the Lake Michigan basin Eastern Wisconsin northern Michigan western New York and southern New England on the other hand have more rolling surfaces underlain by till having a high content of stone and sand In a few areas especially in southern New England and in the marginal moraines elsewhere the till is so very stony as to impede cultivation

Outwash Some of the debris transported by the ice is carried out beyond the glacial margin by streams of meltwater This material called outwash may be deposited as a floodplain (here called a valley train) along a preexisting valley bottom or it may be spread broadcast over a preexisting plain in a form similar to an alluvial fan In either case the surface will usually be smooth with the features that are typical of such alluvial plains Unlike the heterogeneous unsorted and unstratified till outwash material is usually distinctly layered and well sorted in size The fine material of silt and clay size is carried out downstream leaving the coarser sands and gravels to form the outwash deposits Most of the gravel and sand pits that abound in glaciated areas are developed in outwash plains

Whereas much outwash was deposited beyond the extreme limits reached by the ice some was also laid down over already deposited till surfaces after the ice had melted back from its maximum extent Under such conditions the surface of the outwash plain is sometimes pitted and lake strewn the depressions having formed as a result of the melting of relict ice masses that were buried by outwash deposition

Patches and ribbons of outwash are common in glaciated areas and in a few places into which unusual quantities of meltwater were funneled there are very extensive sandy plains Noteworthy in this respect are the southern Michigan and northern Indiana area and Europe immediately south of the Baltic

Lacustrine plains Also present in and around the glaciated areas are numerous lacustrine plains marking the beds of former lakes that resulted from the blocking of rivers by the glacial ice itself During the melting of the last ice sheet while the St Lawrence and other northward flowing rivers were still ice dammed the Great Lakes basins were much fuller than now and overflowed to the southward When lake levels were eventually lowered lacustrine plains were exposed notably about Chicago at the western end of Lake Erie and about Saginaw Bay in Michigan One of the most featureless plains of North America occupies the former bed of an immense lake (Lake Agassiz) that was present in late glacial time in southern Manitoba northwestern Minnesota a tern Nort



Fg 9 8 d g ■ try i th M i De rt th te C lf (Sp A Phot)

ba n fi s h a ter t c of th t el mat c e lm Fo th s on th y ly l lly u eful t m n in pite f tle la g m nt l m th } d that th y fi rd Th h wev m ny important a u lly th b e of the m t n o l ng th ou of th f w tream tl t h v w der d fr m m t adj e t reg s

[E R HA]

B bl g phy \ C F n h, G T T ew rth A H R b d E H H mm nd *El m t f G g phy* 4th d 1957

Planck s constant

A f nd m nt l phy l ta t wh h pr ents th l me t qu tum l t t h g d fined a gy mult pl d by t m l t d e d b M x Pl k 1900 t b th val $h =$ 66 $\times$ 10 ■ r 6 624 $\times$ 10 1 ul The ymbol *h* *met m* *all d th D a h s l* t ed (n e n t hy t l n t th q nt ty *h* wh r = 1416

Th u q e f twe f Pl n k ta t t th u e b Pl ck d t g h ad t n law h m lt pl ed by th l eq e y l ad at n ■ tted bu dl f n gy th t t a q a tum f gy R d nt n gy t ny w ngth ca o nly mult pl f th n ■ thu e gy q t d Th wa a fu dam ntal d partu f m tl bel f f phy pt Pl k t m d w d ed q t t tl g t Pl k h m lf Unt l Pl k ded d h l w to at fy exp ment l d t th gen t l bel f w s that ne gy ld be d ded d fin t ly Th q ant zat f gy m gled by Pl k h ta t l d th f d t l ght po wh h mu h f modern phy h s fib sh d The f qu ncy of m tted radi tion is el ted to th q nt ed e gy ΔE by th r l tio $\Delta E = h$

The co ept f en rgy q a tizat n fi st began to w n ge ■ l a eptanc after 1905 when Albe t E t h w d that it ga a g od cc ur t of s me f th tl p zzl ng f atu s f the photoelect c effect Later A H Compt ■ h wed that the el tro- m gnet c qua ta l o try m ment m p wh h is related to the wa l ngth λ by $p = h/\lambda$

F n te ded d s on of Pla ck s rad at ■ law HEAT RADI TION F a d n f the r l f Pl nck s c ta t t theoret cal ph s *see* QUANTUM MECHANICS *S e ls* ATOMIC CONSTANTS

[H G S P J W]

Planck s radiation law

A law of phy s wh h g ve the p ct al energy d t b t n f the h t r diation em tt d f om a so-call d bla k b dy at any tempe t Discov r d b Ma Pl nck ea ly in the tw t eth entury th l w l *id th f u* t on for th d nt of the q nt m the ry b a e it w s th fir t phy al law t po tulate th t l ct magnet ne gy x ist n d s ■ b ndl qu nta Fo an x t ded d s o *s e* HE T RADIATIO S ls QUANTUM MECHANICS

[H G S P J W]

Plane

1 the el dean d fin t n a rf e s that wh ch has l ngth d bre dth o ly a d pl ne u f ce f e wh h l s eve ly w th th t a ght l o tt If A d fi to f pl ne that a d this mewh t loc ely defi ed c pt f a u f c

ence at the upland level of very resistant strata of rock that have permitted only the most powerful streams to cut through Hence tablelands are predominantly a dry land terrain type Those that do occur in rainier climates usually indicate the presence of an exceptionally resistant cap rock layer

The cliffs and escarpments that are common features of tableland regions are sometimes fault scarps produced by the breaking and vertical dislocation of the crust during uplift More often however they are simply steep valley sides that have retreated long distance from their original positions under the attack of weathering and erosion Sometimes a once extensive tableland will have been so encroached upon by the wearing back of its bordering escarpments that nothing remains but a small flat topped mesa or butte

Tablelands are the least widespread of the major terrain types presumably because of the restricted circumstances under which they can develop The most extensive examples occur in the American continents Especially noteworthy are the Colorado Plateaus largely in northern Arizona and southern Utah which represent a complex erosional plain that has been greatly uplifted and then deeply carved by the Colorado River and its major tributaries Preservation of large sections of the upland plain has been favored by dryness and by the presence of nearly horizontal resistant rock strata The few major streams that have cut deep canyons are all fed from moister mountainous areas round about

The Columbia Plateau in eastern Washington is a porous lava plain cut by the Columbia River and a few tributaries The northern Great Plains lying east of the Rocky Mountains from Nebraska northward into Alberta are an old alluvial plain now crossed by valleys of moderate depth that have been cut by streams issuing from the Rockies The Patagonian Plateau of southern South America is a somewhat similar surface locally reinforced by extensive lava flows Part of the upland of interior Brazil though in a moist environment retains a tableland form because of the resistance of thick sandstone beds at the upland level

Though there are significant exceptions tablelands as a group suffer in their economic development from the difficulty of passage through their narrow gorges and across their numerous escarpments and in most cases also from the dryness of their upland surface

Plains with spaced hills or mountains These are much more widespread than tablelands and largely represented in each continent Surfaces included under the general heading vary from plains studded with scattered small hills and hill groups to mountain and plain country in which high rugged ranges occupy almost as much space as the plains between them

Surfaces of the general type can be produced by two quite different lines of development (1) They may be high relief land that have been brought to the erosional stage of early old age in which case the isolated hills represent the only remnant of a once extensive highland (2) They may represent areas in which separated hills or mountains have been constructed by volcanic eruption or by folding or buckling of the crust the land between them having remained smooth from the outset, or having been smoothed by erosion and deposition since the mountains were formed

Examples of the first course of development are limited in the United States to small areas in southern New England and in the Appalachian Piedmont just east of the Blue Ridge Many patches occur in the glacially scoured sections of northern and eastern Canada and similarly in northern Sweden and Finland Extensive areas are found in the southern regions of Venezuela and Guiana in the upland of eastern Brazil and especially on the uplands of central and southern Africa

In such areas the plains are typical late-stage erosional depositional surfaces usually gently undulating The remnant hills (monadnocks) rise abruptly from the plain like islands from the sea. Although monadnocks commonly represent outcrops of unusually resistant rocks that have withstood erosion most effectively many are not thus distinguished but owe their existence solely to their position at the headwaters of the major stream systems where they are the last portions of the highland to be reduced

Surfaces on which spaced mountains have been constructed by crustal deformation or volcanic activity occur extensively in the great cordilleran belts of the continents and rarely outside of those belts The largest of all such regions is the Basin and Range section of western North America which extends without interruption from southeastern Oregon through the southwestern United States and northern Mexico to Mexico City The majority of the rugged mountain ranges of this section are believed to represent blocks of the crust that have been uplifted or uptilted and then strongly eroded The plains between them are combination erosional depositional surfaces some of which have clearly expanded at the expense of the adjacent mountain As the mountains have been reduced by erosion there have evolved at their bases smooth gently sloping plains that are in part erosional pediments closely akin to old age peneplains and in part piedmont alluvial plains Many of the basins have interior drainage and in these the floor is likely to be especially thickly alluviated and to contain shallow saline lakes or alkali deposits in its l... part

Other areas of somewhat similar terrain are found in the central Andes in Turkey and the Middle East and in Tibet and central Asia The Tibetan and central Andean sections are noteworthy for the extreme elevation (12 000–15 000 ft) of their basin floors In general the ranges and basins in the Asiatic areas are developed on a grander scale than those in North America

It is a curious circumstance that practically all these regions are dry ar ... the intensel... eroded mountain l...

served per od of r ol t n *P* The e lat v d s tan es bey appro imat ly an emp rical law di c er d by J D T tius and publ l ed by J E Bode i 1772 it m y l e xpres ed by the f rmula = 0 4 + 0 3 × 2 if a is n AU and n s et qual to −∞ f r Mer ury 0 f V nu 1 f r Earth 2 fo M nd s f rth Th c mputed and b erved d t nc s gi n Table l

Alth ugh Bode s l w wa d in the pr di t o of the orb t f Nept ne the act l d t nc fall h t of the tl e reti al alue and th d c epa y s t ll g at r i the ase f Plut (ee Fig 1)

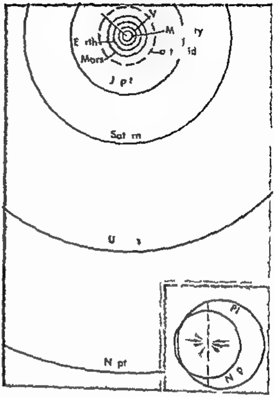
Planetary configurations I the c u e f the m t ns d th Su E rth a d ther pl nets occ py a r ty of l ti p siti n r o fig r ti s (F g 2) the p i c p l of which are de i nated a f ll w th t r pla ets a e in c n ju ct w th the Sun whe lo est t the Earth S nd rect on th l etw e th E rth nd the S n (i fe o c nj n ti n) beyond th Su (sup ti r co j ct) O r r occas ons wh tl e pl et i ery clo t th plan of th Ea th s o b t the t me f n nf o onj ct on a t a sit i f o t of the Sun s b erved S TRANSIT (ASTRO OMY)

B tw j n ti the angul d stance from th plan t t th Su the lo g t n r s p t ma m m val the gre t t o ma mum l ngat s f Me c ry a d V nu a e 28 a d 47 e p i ly Th xte pl ts r ot l m ted and th r l gat an re ch p to 180 wh n th y r in pp iti n with th Sun when th f gat s ±90 the pla t r qu d r t e (ea te o w st rn) with th S

The tel p c p t f the di k of tl e pla ts es c d g t th r fig ti n wh h de r rm n th ngle b t n the d rect n f illu m nat n d ob rvat on r th pha ngle Be tw n nf c jun t on nd g te t elo g t the nt r pla t sh w e c nt phases l ke th Moo b tween ew moon nd fir t r last qua te *betwee* gre test el ngat ns I p i r ju ct n th y h w gibl u ph s l k the Moo n b tw n q t r d full mo At p ju t th h w a t ul r d k f ll) llu m ated a d e f c n h le d g t a s ts th d k d p fil d ga n t tl Su Th ex r pl i h w th i f ll ph b th n l t a d ppos t a d a g bbo s pha n a q d t re f the ll m t d f t is m m m

Tbl 1 Di t ces of th pl ets f om Su (AU)

((	Bod La	Observed
M cu y	0 4	0 39
V	0 7	0
Ea h	1 0	1 00
M rs	1 6	1
A j	8	9 (m)
J i	5	5 0
Sat rn	10 0	9 5
U ra	19 6	19
N p	38 8	30 1
Pl t		39.5



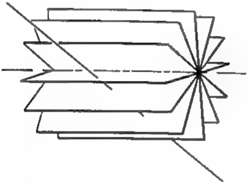
Fg 1 Plo f th ol sy t m

Apparent motions The c mb at ons of the orb tal m t on of Ea th nd f any other pl net gi e ri to c mpl cated ppa e t moti ns of the pl nets a ob rved f m the Ea th Bec u e the o bits f th main pla et ar except fo Plut little i l ned fr m the pla e of th rb t of Earth the pp nt path of the plan ts (cept Pluto) are st t d t the z di a belt 16 wide c n te d on th cl pt c The cl ptic the j th n the sky tra d ut l y the S n m its appa ent an n al journ y as the E rth vol e a nd it (s e ASTRONOMICAL COORDINATE SYSTEMS) Al ng tl s path the app re t m tions f the i ter pla t with r p ct t the Sun a e alternati ely w twa d f m g e test el gat n th ough infe i o j nc t n t great st elong ti n th astwa d f om gre t t el ngati thr gh p co jun ti n to g eat t elong t The m t n f the e t ior pl n ts alw y w stw rd (e F g 3)

Th app r nt mot n w th r *pe t to th l s-* t l ph re that t th fix d t r pp a fo th inte io pl s cillati s b k d forth abo t the po t n f the S n st d ly mo g e st w rd m g th st r F th xt o planet th pp r nt m ti n i g ne lly tw d o d t it i estw d o retr grade At t me whe th d re t on of the ppa nt mot on n th phere b g th pl net pp t be st t ary

Th a interval of t m b tw n es i tu s to th am pl w th e pect to the st rs i the d r al p d wh h go e th tr mo- t o f r lut o f the plan t on t b t und

is as follows: A plane is a set of at least three points not all collinear such that if any two points A, B of the set are given, all points of the line AB are in the set, and such that if any four points A, B, C, D of the set are given, then at least one of the pairs of lines AB and CD, or AC and BD, or AD and BC have a common point. (This last restriction prevents a plane from occupying all of space.) Still another definition is this: A plane is the locus of points each equidistant from two points in space. Points or lines in the same plane are called coplanar. Each two planes are congruent. Two planes that have a common point have a common line. (This is not true in spaces of more than three dimensions.) There is one and only one plane that contains (*a*) three given noncollinear points; or (*b*) a given line and a given point not on the line; or (*c*) two given intersecting lines; or (*d*) two given parallel lines.



Coaxial planes and one intersecting line.

Although a plane is unlimited in extent, it is usually represented by a parallelogram or other plane figure in a drawing. Three or more planes that have a line in common are called coaxial planes (see illustration). *See* ANALYTIC GEOMETRY; GEOMETRY, EUCLIDEAN; LINE; POINT. [J.S.F.]

Plane table

A tripod-mounted drawing board on which topographic survey details are compiled in the field. The table and affixed manuscript sheet are oriented at a point represented by a point on the sheet. Stadia sightings with an alidade locate additional points by direction-distance observations. Points also are located by intersections of the sightings from two different plane-table points. Sufficient additional points are observed to permit sketching planimetric details. Elevation differences also are observed for contour sketching. *See* ALIDADE; TOPOGRAPHIC SURVEYING AND MAPPING. [R.H.DO.]

Planer

A machine for the shaping of long flat or flat contoured surfaces by reciprocating the workpiece under a stationary single-point tool or tools. Usually the workpiece is too large to be handled on a shaper.

Planers are built in two general types: open-side or double housing. The former is constructed with one upright or housing to support the crossrail and tools. The double-housing type has an upright on either side of the reciprocating table connected by an arch at the top.

Saddles on the crossrail carry the tool which feed across the work. A hinged clapper box free to tilt provides tool relief on the return stroke of the table. A variation is the milling planer; it uses a rotary cutter rather than single-point tool. *See* SHAPER; *see also* MACHINING OPERATIONS; WOODWORKING. [A.S.]

Planet

A small solid celestial body circulating around a star, in particular our Sun. Beside Earth, the eight known main planets of the solar system are Mercury, Venus, Mars, Jupiter, Saturn, Uranus, Neptune, and Pluto; in addition, over 1600 minor planets or asteroids circulating mainly between the orbits of Mars and Jupiter are known.

Classification. There are two main groups of planets: the small terrestrial planets—Mercury, Venus, Earth, Mars, and Pluto—and the large or major planets—Jupiter, Saturn, Uranus, and Neptune. The asteroids may be the remnant of a very small planet (or planets) of the terrestrial group. Each of the main planets from the Earth to Neptune is accompanied by one or more secondary planets or satellites. Pluto may once have been a satellite of Neptune.

The planets are also divided into interior planets, Mercury and Venus, circulating inside the Earth's orbit, and exterior planets, from Mars to Pluto, circulating outside it.

Kepler's laws. The motions of the planets in their orbits around the Sun are governed by three laws discovered by J. Kepler at the beginning of the seventeenth century.

First law. The orbits of the planets are ellipses of which the Sun occupies a focus.

Second law (law of areas). Equal areas of the ellipse are described by the radius vector from the Sun to the planet in equal intervals of time.

Third law (harmonic law). The squares of the periods of revolution P are proportional to the cubes of the major axes of the orbits $2a$, so that for all planets the ratio P^2/a^3 is equal to a constant. The ratio is equal to unity if a is in astronomical units and P in sidereal years. One astronomical unit (AU) is the mean distance from Earth to the Sun and is approximately equal to 93.5×10^6 mi.

The constant of the harmonic law is given by Newton's law of gravitation as $G(M+m)/4\pi^2$, where M and m are the masses of the Sun and the planet, and G is the constant of gravitation. *See* GRAVITATION.

Kepler's laws are true to a first approximation only when the mutual perturbations of the motions of the planets by the others are neglected.

Bode's law. From Kepler's third law the relative mean distances (semimajor axes a) of the planets to the Sun can be derived from their

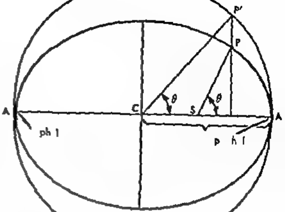
rd ate (f r e mple by m of the merid n (l n tr nt) e d to dete m the ele- m t f their rb t I p e ple thre ob erv t f t o oord tes (ght a nd le l natı n) a d the laws f ell ptic m t on ar nt to dete m ne th ix ndep ndent el ment of a plan t ry orb t nc by Keple th rd law $a \propto P$ In pra ti e m ny ob rvati ns a po bl e c nl d nd the eq at on l ed by the m th l f least quare (s LEA T SQUARES METHOD OF) th elem t f a g n ep ch o oltan d a e ubj ct t r at ns and c rre t n all g f r planeta y p rturbat o T bles f the m ti f the pl net f r l ce t r es pa t nd f tu h be n e tabl hed f m wh h the y a ly eph m r de tra ted in a f rm co en t f r imm d at S e EPHEMERIS NAUTICAL AL IANAC

The el m ts f th pla ets y rbit re g n Tabl

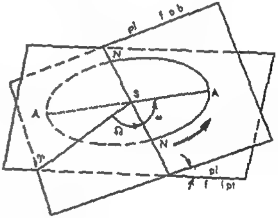
Planetary sizes The app e t d ameter f a pl net m y b d term n d ally by me n f l r m et r p ef r bly a b efring t d ble ma e m mete ttached t t l c y t may b mea ed n la ge al ph to r pl If th ppar t d meter f pl i d wh n it d ta c t the E rth Δ th l n d am t r $D = \Delta\ d = \Delta d$ 206 265 wh re d t m u d n eco ds f r Th l ea d am ter xp ed n th ame it a Δ wh h g e by the ph m d tr om l t s on to m l k l met g e by th d pt d alu f th t m l u it 1 AU = 93 5 × 10 m = 149 6 × 10⁶ km

Whe p l fl tte ng t eptibl l th th po- l r d t ral ad n be d te m ed n Tabl 3 th mea r d = 14 +) a d th ll pt ity = (1 — r) Th mea d u m y al b xp e d t rm f the mea d u f th Earth (3759 m) a a it Th l t e a a then y e ly equ l t a d th l t e ol m t

Masses gravity and density The ma s of a pl n t fo d e ly f t h on m r a t l lt If t the m d t n (mim) x s) of th at ll te a b t d P t pe d f e l t xp d e p t ly n t om l it nd



Fg 4 Ell pt m to

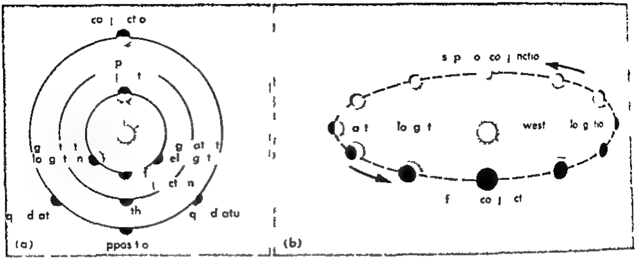


Fg 5 O bt l l m nt

id al ye the ma s m of a pla et i g ven th ugh N wt s law of g v tat n by m = 4 P n term f the ma of the S n as a un t Th a ume th t th m f the sat ll t r lati e t th pl n t nd of the Ea th elat e to th S n m y be n gle t d whi h n ly alway th ca e w th n th ur cy of th d ta S c th rat o

T bl 2 Elem t f pl t ry rbit

Pl et	Symb l	M d t (sem AI)	d t (10⁶ k)	S d eal period f l t (ye rs)	S d eal period f l t (d y)	Sy d pe od (d y)	M loc ty (k /sec)	F t ty (poch 1900)	I lnat (poch 1900)
Mer	☿	0.387	5 9	0 11	87 97	11 88	17 90	0 0f	00
)	♀	0 _3	108	0 61	4 0	583 9	3 0	0 007	3 4
f th	♁	1 000	149 6	1 000	36 6		9 80	0 01	0 00
M rs	♂	1)	— 9	1 881	686 98	9 94	4 14	0 093	1 1
J) ter	♃	5 203	8 3	11 86	433 59	398 88	13 06	0 018	1 18
S t	♄	? 16	14_8	29 4 8	10 9	3 8 09	9 6	0 0 6	30
U n	♅	19 0	9	84 018	30697	3f9 66	6 80	0 04	0 46
N tt ne	♆	30 09	1198	164 8	60181	36 19	43	0 009	1 4
Pl t	♇	3)	910	18 4	90 00	366 4	4 4	0 4	I 09



Fg 2 (a) Planetary co fgurat o s (b) Phase of nte o pla et

the Sun The mean interval of time between suc cessive returns of the ame configuration with re spect to the Sun (for example conjunctions or op positions) is the synodic period which governs the apparent motion of the planet as seen from Earth (see Table 2)

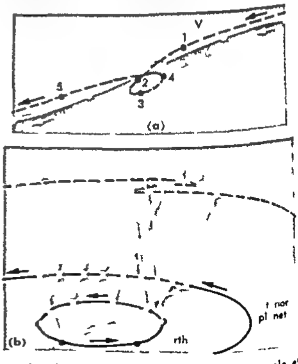
Elliptic motion The motion of a planet having an elliptical orbit of emimajor axis a with the Sun at the focus S brings it e ery half revolution to the perihelion A and to the aphelion A the points of the orbit respectively nearest to and far thest from S If C is the center of the ellip e the emimajor axis is $a = CA = CA$ the eccentricity of the ellipse is $e = CS/CA = CS/a$ whence $SA = a(1-e)$ $SA = a(1+e)$ (*see* ELLIPSE) The di tance $SP = r$ of the planet to the Sun at any other point is $r = a(1-e\ )/(1+e\cos\theta)$ where the angle $\theta = \angle ASP$ is the true anom aly If P' is the point on the principal circle of radius $CA = a$ who e projection in the ell p e is P (see Fig 4) the eccentric anomaly s the angle $\theta = \angle ACP'$ so that $r = a(1-e\ \text{co}\ \theta\ )$ If the planet was at perihelion at time T and re turns to it at time $T + P$ the mean angular ve locity (or mean motion) is $n = 2\pi/P$ and the mean anomaly at any time t is $M = n(t-T)$

The relation between the mean and eccentric anomalies $\theta - e\sin\theta = M$ is known as Kep ler s equation its solution gi es θ and c n e quently r at any time t when the orbital elements a e n T are known

Orbital eleme ts The po iti n of a planet i its orbit and the po ition of the orbit in pace is completely defined by e en o bital element (ee Fig 5) (1) the emimajor axi a (2) the ec centricity e (3) the inclination i of the plan of the orbit to the plane of the ecl ptic (4) the lon gitude Ω of the a cending node Λ (5) the angle from the a cending node Λ to the perihelion A (6) the idereal period of re olution P or the mean (daily) motion $n = 2\pi/P$ and (7) the date of perih eli n pa age T or ep ch E *See* ORBITAL MOTION

If the plane of a planet orbit i incli e l to the plane of the ecliptic their inter ection $\Lambda\Lambda$ i the line of nodes in its motion the planet cro ses the plane of the ecliptic from outh to north at the ascending node Λ and from north to outh at the descending node Λ The longitude of the ascend ing node is the angle $\Omega = \angle \Upsilon S\Lambda$ mea ured in the plane of the ecliptic from the vernal equinox Υ The longitude of perihelion is $= \Omega +$ $\angle \Upsilon S\Lambda + \angle \Lambda SA$ the econd angle being mea ured in the plane of the planet s orbit (ee Fig 5) The location of the plane of the orbit in pace i de fined by i and Ω the orientation of the ell pse in this plane by its form by e and it ize by a the po ition of the planet on the ellip e by P and T (and by the time t)

Dete mination of orbital elements Accurate ob ervations of the positions of the planet with re spect to the tars (for example as mes ured on photographs) or with respect to the cele tial co



Fg 3 App t m t o (a) of a te or pla et w th p ct to th S and (b) of a e t r o pla et w th p ct t th f d st

mea ured (U u Neptune Pluto) the theo et c l bla k body temp ra tur ca le de i ed fr m the kn w v lu f the olar nstant d the l ws of le t r d t on

N th rm l ad em i at met r w ele gth h s bee re e ed fr n Jup t r by means f large r d o tele c pe Th s emi i n tak s the form of ir regular b r t of n i rig nat g i th planet atm phe e f om ubja e t ou ces but ts exa t o g n a d me hani m r t ll unkno

Possible unknown planets D r g the n ne tee th c ntury a unexpla ed i r gularity i the m t on of Mer ry w th ght l y on t be cau d by a unknown pl et cir ulat ng b twe n the Sun and Mercu y call d Vulc wh h wa l oked f r in a n Th s i reg l rity wa at fac t r l pl ed in 1915 by Ein t g ne al th ry f elati ity (se RELATIVITY) It i now c r t n that no tra Me cu al plan t of i e compa bl to th t t ial planets xi t

Th p ib lity f one o more pla et irculat i g beyond the rb t f N ptu e a d Plut h s al be d cu ed but the n c n lus e i d ce f th ex ten e f t ans-Pl t n an pl nets

Planets outside the solar system Minut per t l t n i the ll pt c m t o f s me arby do ble t r h i di at d th e i te ce of m o omp n nt of m ll ma the e y t m The m f these atell t b d alth u h larg r tha pla et ry ma n the olar y tem a e d red t be too m ll t l elf lum no s th y a con equently m e l k plan t th n dwa f ta s F m th s es d nc t nfer ed that pla et ry sy tem ar t s un m n i th i e s was pre u ly bel eved b t n el able i m te f the f equ v of s l y tem ca l made s y t Wl ether som l the planets attend ng oth ta s a e hab table by ad d bei g o tai me l w r form f l fe u kn w the doctrin f the pl l t f nh b t d w lds m a pl u ll b t p ed phil phi l pecul ti

F d t l d f mati the ma pla ets s JU ITER MARS MERCURY (PLA T) NEP T PLUTO S T URANUS VE US e l o A TR ID ASTRO N IC L I STRUMEN S CELES-TIAL ME I NICS CERE E RTH ORBITAL M TION EROS PR ESS TION (ASTRONO Y) PLANET R TIFICI L RADI ASTRO O Y SOLAR SYS E TRO-JA PL NET

[G D]

B ll g phy H N Ru ll R S Dug and J Q St w rt, *A t my ol* 1 1945 W M Sm t *C l l M A* 19 3

Planet artificial

A ma m d bject l hed to b t d th S n t CELESTIAL ECHANICS) The fi t t rtifi l pl n t t fi l sol r t ll te r Mecht (l ll l L k) la ch d J nu y 2, 19 9 l th S t U n and P IV l un hed t th U t d St t n M h 3 19 9

Mechta n lud g t fi l t g w ighs bo t 3300 lb (wh h t t m t t n a d th

Pl t d P e V o 26- phe q pped w th f p dd s o h ry 1200 lo e lls to p o- de p w f th 150-w tt od o tr m tt r d as- o t d e e t fc t m t Th 95-lb ll te w l n hed M h 1960 to o b t th Sun betwe E rth nd Ve s (NASA)

p yl ad Appr ximat elements of the o bit are a mim j r a is of bout 107×10 mi a p i d f 450 d y an li at on f 1 an e centr ity of 0 148 a per heli n d tan e of 92×10 mi with ep h of fr t p ssage the m ddl of Janu ry 19 9 and n apheli n di t ce of 124×10 mi with epo h f fi st pa s e ea ly Sept mb r 1959 Mechta wa lau h d wh n Earth was at pe ih li n and at a t m t take f ll ad antage of b th the el city of E th a d the p ition of th Moon

P o ee IV l unch d to tudy furth r the r d a t belt about Earth and to determ e f other su h eg on l e fa the in sp ce tha pr usly p bed s l o tr ked by tat ons in several na t ns N additi nal maj r ad ti n b lt wa de t ted by its tw G ger M ll r co nter Among d t ad oed b k f m the 13-lb n t mented con w in ide t mperat re in the v i ty of 41 C. O b t l el ty i c mputed f om la ch t aject ry to b 69 400 mph mi a jo a of ab t 98×10 m l s a pe od of 392 days a p hel on dis- t f 91 744 000 m w th fi t pa age al o t M ch 17 1959 nd an aphel on d st n of 105 829 000 m with po h of fi st p s a e l te Sept m b r 19 9 S SATELLITE, ARTIFICIAL SPACE VEHI CLE

[G D V]

Planetarium

A pr j t de wh h f thf lly p rtrays the h e t any time i th pa t p ent, r futu A pl n tari m is e s t ally a m lt ple l d p o ject a typ al pr du ing m e tha 110 pa ate m ge on an inte spher cal p je t reen d m At pr te end of a typ cal p o- j ll in tr ment tw l g b ll each c n t i ng 16 p jecto (F g 1) The e pr ject nt the h t m t l d m h d 32 p cture wh h

Table 3 Physical elements of planets

Planet and symbol		Equatorial radius r km (♁ = 1)		Ellipticity = 1 − r /r	Volume (♁ = 1)	Mass (♁ = 1)	Density g/cm	Escape velocity km/sec	Rotation period	Tilt of axis
Mercury	☿	0 38	400	0 000	0 055	0 0 3	5 3	4	8 9 d	small
Venus	♀	0 97	6 00	0 000	0 91	0 815	4 9	10 3	weeks?	3 ?
Earth	♁	1 00	63 8	0 0031	1 00	1 000	5 52	11 2	3h56m4 1s	[illegible]
Mars	♂	0 53	3400	0 00	0 150	0 107	3 9	5 0	4h3 m	[illegible]
Jupiter	♃	11 20	71400	0 062	1317	318 00	1 33	61	9h 0m30s	3 1
Saturn	♄	9 4	60400	0 096	769	9 2	0 69	3	10h14m	[illegible]
Uranus	♅	3	3800	0 06	50	14 55	1 56		10h49m	98 0
Neptune	♆	3 50	2 300	0 0	4	17 23		25	1 h40m	[illegible]
Pluto	♇	1 ?	6400?	?	1 ?	0 9	5 ?	10 ?	16h	?

To perpend cular to orl t
Latitude <1 (system I) 9h 5m40 6s lat tude >1 (system II)
Near Equator 10h38m at inter ned ate latitudes
Colons ind cate uncerta n dete minations

m / M of the masses of the Earth and the Sun can be determined imilarly planetary masses are also known in terms of m

If the planet has no atellite (Mercury Venus Pluto) its mass can be derived only from the per turbations it causes in the motions of the other planets and occasionally of comets Since the per turbations are small the masses o obtained are generally of low accuracy

Once the mass m and the radius r of a planet are known in terms of the Earth s mass and radius its surface gravity and mean density relati e to the Earth are given by $g = m/r$ and $\rho = m/r$ respec tively Multiplication by 981 and 5 552 gi es the co responding values in cgs units

From r and m follows also the e cape velocity V_1 permitting a projectile (or a molecule) to lea e the planet on a parabolic orbit $V = (2Gm/r)$ this i $\sqrt{2}$ times the velocity of an hypothetical satellite moving in a circular orbit close to the sur face of the planet (*see* ESCAPE VELOCITY) The elements are li ted in Table 3

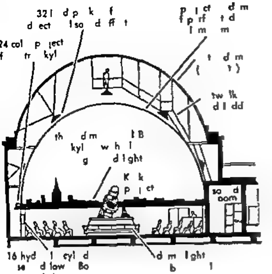
Rotation periods The period of rotation of a planet i best determined by direct telescopic ob servation of the permanent markings on its urface (Mars Mercury) of the semipermanent cloud formations in its atmosphere (Jupiter Saturn) When no definite detail can be een on the disk (Uranus Neptune) the pectro copic determina tion of the velocity difference between the opposite equatorial limbs can gi in combinati n with the linear diameter an approximate value of the r tion period unles it i o long (as i the a e with Venu) that the hift of the pectral line i not measurable Finally when the apparent di ameter of the di k is too small for either of the e t vo methods (Pluto asteroid) a determi ati of the periodicity of the light variat ons if any due to the changing pre entation of brigl t and dark regions of th urface may give a fa rly acc rate value of the rotation period The rotati n is n w rea onably well kno n for all main planets ex cept Venus a indicated in Table 3

Planetary radiations The electromagnetic ra diation received from a planet is made up of three main components the visible reflected sunlight plus some ultraviolet and near infrared radiati n the thermal radiation due to the planet s heat, in cluding both infrared radiation and ultra hort rad o waves and the nonthermal radio emi ion due to electrical phenomena if any in the planet atmos phere

Planetary brightness The apparent brightne of a planet can be measured by vi ual photo raphic, and photoelectric photometry and is u ually pressed in the stellar magnitude cale it varies in inver proportion to the squares of the di tances to the Sun and Δ to the Earth The fracti n of the incident light reflected at full pha e compared with the fraction that would be reflected under the same conditions by a perfect diffuse reflector i called the geometrical albedo It i a mea ure of the reflecting power or reflectivity of the planet s surface The visual albedos of the planets ary be tv een 5 and 70% *See* ALBEDO

Planeta y atmosphe es The chemical compos tion of a planetary atmosphere i derived from spectroscopic studies of the ab orption band if any pre ent in the sunlight reflected by the planet. The major constituents of the atmospheres of the terre trial planets are carbon di xide water nitro gen and (on Earth only) oxygen of the maj r planets hyd ogen helium methane and ammonia

Heat radiation The heat radiation from a planet can be measured either with a radiometer at wa e lengths of 8–15 μ (which are transmitted by the Earth s tm sphere) or with a radi tele cope at wa elengths between 3 mm and 10 cm In either ca e the amount of energy corre ponds t that wh ch would be received under the ame conditi n f om a perfect rad at of the same size at a certain temperatu e T called the black body temperature of the planet (*see* HEAT RADIATION RADIOMETRY) It relation t th a tual temperature depend on the properti f the atmo pl ere and surface of the planet When the heat radiation is too weak to be



Fg 2 H m ph l pl t m p d l l f p ky t d n (B st M m f S c)

A p f ted hem ph ic l ee wh ch th d m p m t th p j ti n f pe l effect d g d m t at [IML]

Planetary gear train

A seq e f m hed g rs t g f e t l g l t t l r g d o e m n te med te p wh h upp rted e l g l mpl pl t y g th p m l m lt ly w th th t o tal g (F g 1) With th t l g fi d a p t t h t th e t l g r pl t t te ab t it the gea s a m d c ord gly Also w th th n ge fixed t th n a pla t p t ep y l d he th a embly i l m f p l t n The pl t d th p ate t g th nd t t t a ompl t m mbe

l p at t p t p we d m mb r f pl t y g t a d m mb t d e t p d th tput d th th d membe fi ed If t n t fi d n p w t a m tt d

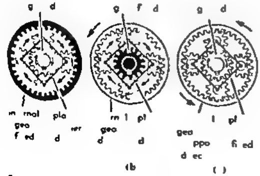
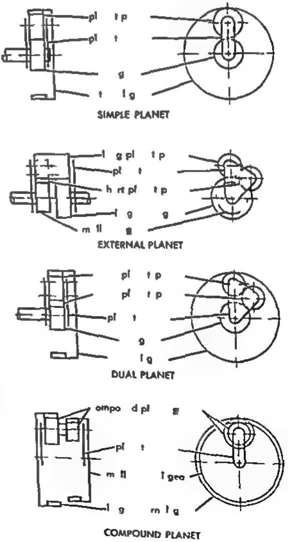


Fig 1 (a–c) Th p pal mod f p t f pl g t

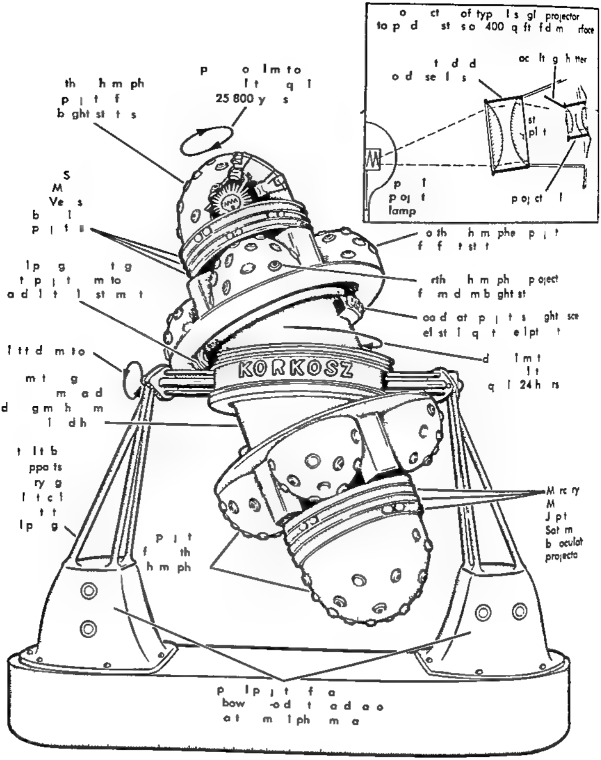
through the ge r trai Th s ch r ter t c pro de con re t cl tch a ti n a brake band around th te med t memb d fi ed to the g ar h u erse t l k or f e the thi d memb r with ut t elf ente to th p th of pow transm n Any of the th elements be fixed th ce t l r the planet c er r the int nal ring ge P wer ca dr eithe of the tw m element a d the other can del the t put Th thu ix c mbi t o f peed rati w th a i le planeta y t i w th three be recip l p t ely f the other three The pri cip l p ed rat s fo a simpl r tra n ar w th nt al ge fi d l rg p d d t on (Fi 1)

$$\frac{\omega_b}{\omega} = 1 \pm \frac{N}{N_b}$$

with s g a fix d mall peed duction (F 1b)



Fg 2 mm g m t f pl t ry g t



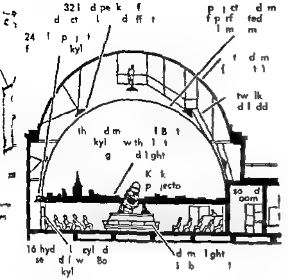
Fg 1 M d planet m p oj ts o er 9600 tar (R s ll H Lo g a d Th Chr t a S e ce M t)

coml ine to form a repre entation of the principal star in both hemi pheres i cluding in the ca e of the largest planetariums tars as faint as magni tude (5

There are ■ en ol je t —the Sun the Mo n and the fi ■ inner planet —which are made to move again t the backgr und of the tar by mean of paired projectors in the cage that eparate the balls from the central p rtion f the instrument

M tor pro ide motion for the planetarium One set turn the in trument to imulate the daily r ta tion of Earth Another et produces annual motion of the S in Moon and planet f rward or back in time Motion around a h riz ntal axi gi ■ the ef fect of change of latitu de Thi permit the ky t be een from any point on the urface f Earth from the North Pole to the South Pole Tl e m t ■ of preces ion of the equin xes the wobl ling m tion of Earth s axi once in 25 800 year can al l e imulated e en to the extent of completing one 25 800 year cycle in 3 min *See* PRECE I N OF EQUINOXES

The planetarium chaml er can l e up t ft diameter and can eat up to 750 pe ple (Fig)



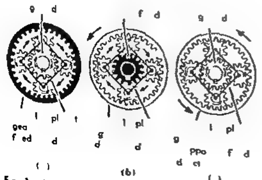
Fg 2 H m ph c l pl t m p d l f o f p ky t d (B st M m f S)

A p rf ated h m ph r l e wh h the d m p m t the p je t f p l ffect d ing dem t t n [I M L]

Planetary gear train

A qu c f m hed ge t g f a ent al g l nt l i g d e r m te m d t pi wh h pp t d e l ng l mpl pl et y g a tle p n m h m lt ly w th th tw oa al g (F 1) W th the ent l g a fi d r n o t te b t th t al g a plan t t t b t t n th a e med d ly Al th th r fix d t th n pl net g t s p y l d he e the mbly a f rm f p l t n The pl n t l th e t ope t t eth nd t t r mpl t m mbe

In pe t put p w d m mb of pl t ry g t a d m mb j d t p d th tp t nd th th d m mb fi d If t t fi d n p w t tr m tt d

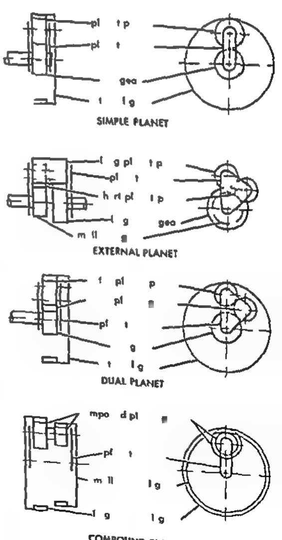


Fg 1 (–c) Th mpl g tr p p l m d f p f

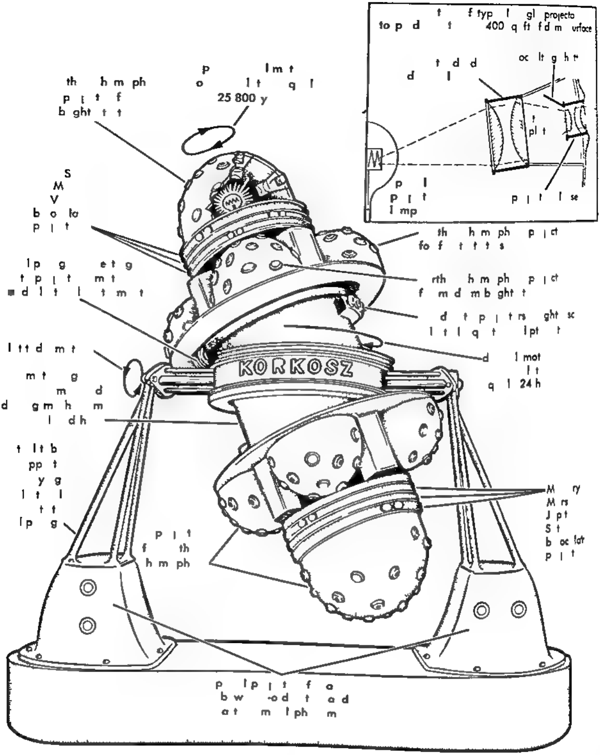
ll o h the gear t ai Th el aracter t c pro de o en ent l itch act a t rake l and aro nd tl e intermed ate memb r a d fi ed to tl gear h u ing erves to lock or f e tl tl rd meml er with ut it If ent ri t the p th of power tran mi i n Any on of th tl re elem nts ca l e f ed the c t l n ge the pl net ar ie r the internal ri g gea P we c d i e e th r f tle two remain ng el m nt a d the ther can del er the out p t The a th x mbinati f p ed rati with a s gle pl n tary g r tr in witl tl ee l eing r ip cal pe ti ely f th otl er tl re The p nc pal peed at os f r mple g ar tr in are witl intern l g ar fixed l rge peed redu tio (Fig 1)

$$\frac{\omega_6}{\omega} = 1 + \frac{\Lambda}{\Lambda}$$

with u gear f xed mall spe d r d ti (Fig 1b)



Fg 2 F mm g m t f pl t y g t



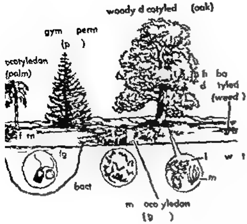
Fg 1 M d plo to um p j ct o e 9600 sta (R ell H L g a d Th Ch t a S Mo to)

combine to form a repre entation of the principal tars in both hemi phere including in the ca e f the largest planetarium tars as faint as magni tude 6 5

There are e en ol ject —the Su the M n and the f ve inner planets—which are made to m ve again t the background of the tar l y means of paired projectors in the cage that eparate the balls from the central portion of the in trument

Motors pro ide motion for the planetarium One et turns the in trument to imulate the daily rota tion of Earth Another et produces annual motion of the Sun M on and planet forward or l ack in time M ti n around a hori ontal a i gi a the ef fect of cha ge f latitu d Th i permits the kv t l e een f m any p int n the urfa e f Farth from the N rth Pole to the So th I le The m ti n of prec on of the eq in xe the wol l ling mo ti n of F rtl axi on e in 25 800 year can al l e imulat l a n to the xte t f completing ne 25 800-year cycle i 3 min S I RECE to of FQUINOXES

Tl e planetari im chaml er c n l e up t 5 ft in diameter and can seat up i 750 p pl (Fig I



g 2 Pl t f m

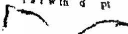
o a l mted chem of gr wth bec u the mbry n r g owth t fi n u ed up i the oc f m tu at (3) Alm t all plant ba e fairly firm t u tu al f am w k of elluio e a mpl x b h d at comp nd wh h a maj r t tu nt of pla t ell w ll M t m l h w ne la k llul and th r lls alm t u i ally l d i soft memb a at e th g d w ll (4) Th a t maj ty of a m l b th p er f l m t ■ wherea nly cert i lo pla t h v th bil ty t mo e fr m pl ce t pl c

Th low f rm f l f th t a not b p fi lly l fi d a e th pla t o m l l a e bee f t ly ll d pl t m l T H Ma b d a d C W M t n b t n t all th lm m ld My myc te th l s lyi g them pl t wh ■ A L t zool g t call th m My eto zoa thu pla g th m the teg y f a m l L k w e rt m b le ll d gre n g m u h a *Chl myd m as* f l and *Pan do* ga d d by th b t n ts pl t b t d ed m ls b zool g t M t b l gi t g ho ■ th t pl nt nd n m l f d m nt lly al k nd h e ol d f m mm ■ to d t f g p r d f tum D lly d ectly pl t pr d m nd h d m t m ls w th ll th food d w th h th prod t lumb rk te t l fiber d g g t bl f gum n r bb p s, pe fum drug b e g dy t n g mat l w nd p p

Pl t g f om m op ne c ll d g m h ba t a d som lg e t g t tr es (F _) F a cl ll t n f the l pl t (m PL T KI GDO I S I PLA T TO Y PLA T P YSIOLOGY FLA T TAXONO Y [P]

Plant mineral nutrition of

M l t t l th p es by wh ch a pl t a g d t l m ral l m t Th n t B f m r l l m ts i r pl nt s t med b rpt f qu ntly so pl n t t a t w th d pt f t h g d u f e



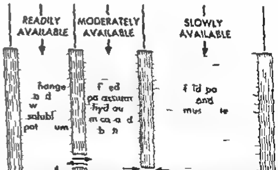
Tabl 1 Siz and d t b t on t soil p rticles l typical lls

k i f pa t l	D m t mm	S dy loam %	Cl y loam %	Cl y %
Coars f	00-0 0	6	30	1
F f	0 0-0 0	0	30	9
S lt	0 0 -0 00	5	0	
Cl y	B l w 0 00	10	0	■

From I Bo l A W C l t n, *P ne pl f l l t Ph logy* W H F eem 19

Sub equ t di trib t n of m ne al w th n pl m i accompl hed th gh tl e p oc f tr n l a t n H gh r land pla t generally a q ire th ir m e als fr m the oot med um u ually m t s l Le ffe t ely they may d i e th e i l tan es thro gh the l a e f m d t a r ls rain and sprays For ab orptio by plant min ral g ne ally mu t be in the fo m of alt and in luti n i wat r d the mineral ■ te tl e plant as di sociat d i

Ionization of minerals in soils The mi eral matt i o l is derived f m pa t rock th ugh w ther ng Partı le ary n s ■ f m nd to clay (Tabl 1) So l st tu e d pend pa ticle i d d t b t n ch m al mp it o m i t re te t e atı and m rob log cal p p lati (e SOIL) In mo t l chemic l c mpound of mine als pass i t queous sol ti Th e m po nds d oc ate to a ■ d gre tl e ns e ist ng f in luti n les freely ad bed t oll id l lay p t les A teady tate ap pr a h d betw e th i ns in luti d th e sso ted w ti the lid ph s (Fig 1) Th ese m n al o s e n mo ■ w thin th s il and int pl t lls o r ots Pla t res dues in the l ur f h r zon m y al o tr bute m ne al matt r i the l or t b qu nt cr p N tr gen n c f m su h a mm n um nitr t nd nitrate ex



Fg 1 S h m t ll t t f l b l ty t g of pl t t ■ o l (mpl f d w th th lem t p to m) d t f m t f om t g ry t a th A r w d t th d ct f t f m t s d th w d the e t th m p d the t f i f m t (F m E T ■ d M f N t n f Pl t U iv f W ■ 1951)

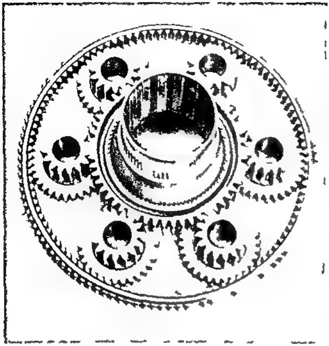


Fig 3 S comp d planetary p ons tran m t h gh powe f om a rc ft eng to prop lle w th about 2 1 spe d educt o (Foot B othe G a a d Ma ch e Co p)

$$\frac{\omega}{\omega} = 1 + \frac{N_b}{N}$$

with planet carrier fixed reverse speed increase (Fig 1c)

$$\frac{\omega_b}{\omega} = -\frac{N}{N_b}$$

where is angular speed N is number of teeth and the subscripts identify the members a for planet carrier b for sun gear and c for internal gear

This speed changing feature i u ed in automo tive automatic transmissions The number of teeth on the planet pinion of a simple planetary gear does not enter into the equations for peed ratio because the pinion engages both sun and ring gear hence the teeth of all gears are the same ize and the number of teeth on each gear is directly pro portional to gear diameter The above eq ations can therefore be expressed in terms of gear diam eters in tead of numbers of teeth

Planetary gear trains can be variou ly m dified for added flexibility (Fig 2) Such gear trai pro- ide large speed ratio in small space With multi ple pinion they tran mit large p wer (Fig 3)

The aircraft engine dri es the outer ring gear of Fig 3 the central un gear is fixed the planet carrier arm omitted in Fig 3 to h w the com pound pinions ha tub haft that carry the planet pinions in the manner of the cage of a ball bear ing The main haft of the planet carrier p e through the opening in the sun gear to dri the prop eller The u e of an internal gear acco nt for much of the power capacity and m th perati n of the gear train See GEAR TRAI

Plant

A common term loosely u ed to de ignate any li ing organi m not included in the animal kingd ... In the higher forms of life a clear di tincti n can be made between plants and animals (Fig 1) However ome of the lo er organi m po e both plant and animal characteri tics

Although no single criterion can be u ed to se arate all plants from all animals certain features taken collectively provide a general ba i for d tinguishing between the two kin dom of organ isms (1) Approximately five- eventh of the 350 000 known plants have chlorophyll a complex of green pigments which enables them in the pres ence of light and air to synthe ize carbohydrate foods Such plants are said to be independent in contrast to bacteria fungi and nearly all animal —organi ms that have no chlorophyll and are therefore dependent upon chlorophyll containing plants for their supply of carbohydrates (2) The embryonic tis ues in most plants are abundant persistent and active thus permitting an almost unlimited growth Most animal on the contrary

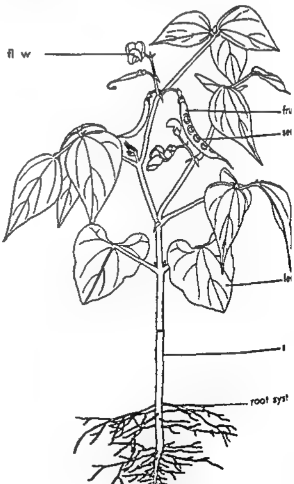


Fig 1 D m of a compl te h bac s d otyle d pl t (b a) sh w g th th p d ct e o ga (fl w f t a d d) a d th th e eg tative o ga (t t m a d le f) (H Wo k b k l G al B t y

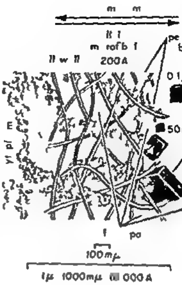
ent at o I onc t t s al influen e al b l ty f ad o bed t n t plant

I m n ral nut t o ilab l ty i u ually a er ı ned by hat lem nt th pla t a q ır d ng owth B cau e of the ı l nt l ı t r l t n l p l l f cto f ı lant d el pment a well ıl e d tı n ı fluence equ t The typ nd xt nt f t de l pme t can ı fl e c pr cu e- ı nt of ı s f m the s ıl Wheth r pl nt w ll evel p d p d n pa t t nd e t nt of ı v l b l ty th l Ma y s l ha e l m ted v ı l b l tv of rt ın ı F r plant n t ıı o nly th e on c m d t al t growth ed b ıd ed The ki d f l m t tı n ıs de- dent th pa t r k mp t n th tru e f the l y m e al l a h g ffect m cro- l g al t ıt es d n r nm t l ndt n Thu ıt ate s lfate m b d f e ı b e e f t ı ted m ob l gı l t ty o le h n ota um m y be l m tı bec l fi at o n lay ll ds pho phate m y be fi d n the ry t l tt ce f l m e l mm b l d by f rma o f ı l ble mp u d as fo x mpl w th l m um o al m cal n m y be d fi ıent ıec of the a d r a tı n f th l ıt al n um (n t e ogn ed t be e t al t gr wth) n y b t ı b e of e a l bıl ty

ANATOMY AND MINERAL NUTRITION

I d d l l g ll f pl t e mplet t f r b pt f m e l t nt Th l g yt pla m b u d d e t rı lly by a ll wall d gen ally nt r ally by a d t aq eo s ıh th u le (CELL ORGA IZATIO) M r l ı ab pt n p s fr m th exte l hath g s lut m d um nt nd th gh th cell ll Th ll wall u u lly p e ble t b th th l t nd l e t Alth gh th m b m t t t m m nt w th th ll wall d ffu th gh t lat ly f e On m y en th sol t ll wall a pp h g n tı ıty q ı al nt t th ext l l t o (m d fi d f o n e t t t llo d l f e n p opo tı n t d rpt) Th th ll wall sol t b m the p t pl m b th g m d m (F g 2)

R t th p rı ry b b g o g n f h gher l nd pl t r mewh t a al g u t th ll Th fa e f oots a b th d by the l r th r lut med m Somewh t l ff t ly (g d t ad lly w d) th t e l ll f oot ı d ıdu fl b thed by th m l ghtly mod f d lut wh t n l tı l mn film r Mod fi t d pe d r t a d d g f att m t f t d t t w th th xter al l tı wh h n t rn d t m ned by the ll w ll p rm b l t th r t f t m l nwa d f l te d wat r d the pply f m t rnal u At the e dod m (th m r l f th r) Ca pa r ıp mp ed f b des l p e ly nd f rm nt l y w th tl t s e e d d l ll ll These t p h ghly imperme-



Fg 2 M d l f b d ry g n of o t su fa d g wth m d m (F m H J y d J G l M d f try f at f m t pl f t S e 128 90–91 1958)

bl to t th l nt nd ol ıte c mp e t f o- l t on Th th cell lay r mu t be cı mı nted by the pas g f m t rıal ınt and th gh y topla m Lat a sım lar ımpermeal le s l tance s la d d w n th tange tıal walls of mo t f the e d d rm l ell the few n t s dıff re t ted rem f r a t me ın th prım y d tı n a p ag ell In tım all endode mal cell may att n the ec d y d tı an effectı e ıf n t mpl t b ıer to ı assag f m t r als r d ally a r ss r ot When th s co d t n obt pen et t n of m e al ı ı t the ylem c du t ıs eff t d l y de elopment f eco dary roots wh h p e e the e d derm Only th m r t m ıs rela t ely f e of u h be ızatı Ev n n thı tı e m ha e gge t d that l m t d permeability z t d e t m d fied ell wall mp t n flu f n m y b l mıted due t po tı n of th me t m ı el t o to the b thıng n ed um or b e the me stem s nclo ed by the ımpe me- able r ot e p Al th ate of cell dı nd l g m t n th m ı tem may be h as to ef fect e nt lly ompl t ab rpt on d t nt o of mı l h h enter th e c ll f m xte n l sou ce Old r r ot le t e phys l g lly a c fte o e ed b laye f o k (ube ed) lls wh h a v ry ımp rmeabl t m eral salt d wat r S b z t n f older ep d rm l cells ıs m l ly r tr tı e O ly f fi su e d lop ıf ute l y a lo gh d ff p meab l ty t m te ls f bl nd b o ıt o ffe ted p d d f o rse that oth r fa t t wh ch ec ry f m em t

h y tem c ll o ntegr t d r t ı dy m d ffe nt lly p bl mot sy tem In d l b l ty f m al t pl nts effect d th gh gr wth r o f oot o t de l pme t f n w r h nd f m t f

Table 2 Effect of growing crop on composition of soil solut on

Soil	Date	pH	Parts per million of di placed solution†								
			NO^-	HCO^-	SO^{-}	PO^{3-}	Ca^{+}	M^{+}	Na	K	Total
Sample 7 1 5% moisture	Apr 30	7 4	149	83	561	1 1	4	91	4	1	1190
	Sept 4	7 6	58	155	[illegible]	0 6	193	4	40	9	935
	Apr 8	6	9	112	699	0 6	336	[illegible]	59	1	1 [illegible]
Sample 11 1 4% moisture	Apr 30	8 2	1 3	160	671	3 3	9	9	8	41	1454
	Sept 4	7 6	16	34	598	1	19	61	44		11 1
	Apr 8	8 1	263	59	785	2 9	6	94	8	3	1793

After Burd and Martin fr m E J Ru ell *Soil Conditions and Plant Crouth* Lon mans C een 19 0

† Solutions displaced by water from cropped oil at be innin (April) and end (September) of growing sea and at the be innin of the next growin season

ist in soils through fixation from air of the oil by means of oxidation reduction processes of bacteria (*see* NITROGEN CYCLE) The ionic state of soil sulfur may be similarly modified

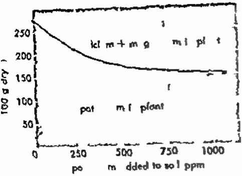
Ion concentration of external solution The oil solution is the natural external solution bathing roots or rootlike structures of land plants Soil compo ition cannot be measured in its natural po sition in soils at moisture contents between the field capacity and the wilting percentage and supporting usual growth Dilute aqueous extracts have been obtained and analyzed from which approximations of oil olution content ha e been com puted Agricultural oils under favorable moisture condition contain about 0 1% of soluble mineral matter The osmotic pressure value of soil olutions varies from about 0 2 to 1 atm total solid vary from about 500 to 2000 parts per million (ppm) of displaced olution (*see* PLANT WATER RELATIONS OF) Even at low oil moi ture content the oil olution of leached agricultural soil is generally very dilute being $\frac{1}{10}$ to $\frac{1}{100}$ the oncentration of sap removed from roots Soil olutions of arid and of emiarid irrigated oils ha e higher salt content The ionic balance in such so ls al o characteri tically differs from that in soils of humid region In the former (arid) calcium and o dium salts of sulfates and chlorides may predominate in the latter (humid) hydrogen ions may be pronounced in the colloidal clay exchange complex Total salt content and ionic balance in oil olutions vary under cropping with partial or complete recovery from plant absorption occurring during fallow periods (Table 2) O er a period of year the total alt content of a oil become depleted under continuous cropping Depletion of the ion content of s il lutions is not always evident from soil olution analysi there i ome renewal through progre sive di ol ing of miner l or replacement from the exchange complex of the oil colloid Ab orption of ph phate r pota ium by plants is not readily reflected by mea ureme t of concentration decrea es in the il olution Much of the upply i derived thro gh progre i e olution from the exchange complex r the parent minerals Maintenance of total salt upply and balance e pecially for nitrate and sulfate i effected al o through acti ities of il micr organi m under ad er e conditions (for example ana r bi i) such activities may lead to depletion of certain ion such as nitrate *Mineral alt olubilities al vary with acidity alkalinity relation* and the moisture content of oil Nitrate and chloride oncentrations vary inver ely with moi ture percentage whereas pho phate concentration though varying from soil to oil is independent of oil moi t re content sulfate i intermediate The relati e proportion of cations in the oil olution depend on their solubilities in the mixture Dilution cause maller decrea in concentration of the mon lent than divalent ion Availability or mobility of e ential elements in olution i the fir t requisite to absorption by roots

Kinds of available ions Es entially all ion present in the soil complex are available in some degree to plant roots Plant analysis hows a large number of different element deri ed from il The e include all tho e e ential to growth a ell as many which serve no required role in de el p ment of plants according to pre ent kno ledge *Theoretically all ions in external* olution are available as well as much of those ad orbed on soil particles Some pota ium other than that readily exchangeable from oil by u ual laboratory chemical mean is derived from the olid phase (Table 3) Availability bears no relation to t l pota ium content or its relative proportion in the soil The mobile con entration (acti ity) and per meability of the medium determine the a ailability Temperature m isture supply and hydrogen ion concentration are factors modifying the mob l

Table 3 Pota sium uptake by crops compared with potassi m depletion in soil solution

P t ss m so l t t pi m				
B f	p sow	M ft p l t l	D pl t of K l s l t pi m	Absorpt f K l y crop ppm
R g	M			
10	8	8	0	101
10-1	1	8	4	8
15 0	17	1	6	116
0-		11	1	133
40-4	41	14	8	161
4	0	16	34	46

I m I J R ell *So l Co d t ns d Pl t Growth* Lo gm s C ee 19 0



3 f t l ff ct m l ab o pt by ts C d Mg bal ff b pt o d m l t f K d (F om R H gl d t ct m th l gu Nut n Pl t Ch o & t o 1944)

ll d m m a u the eby Hyd g a d f y yl a d a b n nd o g n c a d i ns ef t fy fl e th e bal n t th s il It l modified by t mpe at re m tu e ontent d t t of m cr o g t m and plant as ll a by ppli at of fert l s by man Th se te n ffe t d t ch n the kind of a ail bl o s f pl nt t t th r th y modify h r l l f mob l t

With abso pt f m n al alts by pl m nt o ff t e p o ed (F g 3) A d ted lat d f ct aff t ng m n r l t i n f pla t th a l ble le l i ne at n ny mod fy th ab pt o f n th t n o o m l t ati n obt fo an The p e n f d t lent g e ally tards ab pt f m al t Th p en e f p l v) te r h w c n h n e the ab rpt f m m n l t c ti n Eff t f thi t e p b- bly d t th gh nflue s o met b l m f th ll th p rmeab l t

PROCESS OF MINERAL ABSORPTION

Ab pt tl ll p l et mo m t nw d (n t nfl) f m l s fr m an t al l t n med um b th ng c ll t ga h a t t p t pl m thr ugh t t ph nt l t th p t pla m A typ al t l ph ell a u l t th r all t v t m f h gh l d pl t tel (ylem) l St t g lly f th t f mod f d m m t w th th l ing memb e p t pl m nt p d l twe t o q o ph F m d l m r t abso pt n a ed t pl d ff n d ff n x h g d pt n nd m t bol (t) m lat l l f the e m h a ms t l th m g t n l th t l l t r l g fa ult d l t m y m el t e t th th d p nd tly t l t t m l m t g bo d y Th d du l m g ti n l d ti g led fr m m fl w n wh h the tw ol tt a d ai l nt rr t g tl n lat o t m l m ti ng t d y l pl th ugh p p

co t nu us p re y tem Thu a fifth mode f mo e m nt (ma s mo ement) i re gniz d and may l e in l ded in ab rpti tl gh th n tures of the fl x tendenc e d ffer betwe n c n tituent component migrat o and c mp ite fl w

Diffusion of ions into plants Simple d ffu o of mi eral alts will ten l to cur wl ere er a dif ference of co centr tion (acti ity) of olit e t betw e two r g that f m a regi n of g eat r c ncentrati n of the olute t a regi n f it lowe conc ntr t on Thi may in t me lead t eq ality of c ncentrati n of tl e tw regi n (dy am c equil brium) Thi m de of flux acr d f ferentially permeable pr t pla m ften v ry slow The rate f d ffus n depends i pa t on the *pe meabil ty of th m d m a d in pa t on tl e* c nc ntrati n grad ent Diff i n i t d; ectly af fected by i hibit rs f metaboli m n r is it li *re tly d p* dent up n ac d ty (pH) It l as a l w t mperat re coeffic e t cl aracteri ti f phy cal p o e es of mo em t H we er in a ls d ffu ion i ce t nly a fi t tep in l re g *mineral* ion to th ro t urface It probably i effe ti e al n th mo ement of i th ugh cell wall ad rp ti n exchange al o m y l e effecti e l ere Sin e th re appears to be fa ly free diffu on through ell wall nd st ce channel may l e contin u t th tl at h gl m t re le els u l inta t fluid lumns or films may n titute an outer spac ti u m which is d s us ed this rt cle i the e ti n o the *out r r free* pa e nc pt Pr e t *e den e doe* n t war ant o id at n that the ut pac c nti um al o incl des the p to- pl m th gh d ff ions t ke place th ei S m *alt though little* d e m a ro s prot pl m by d ff o when m tab lic acc mul tion is hib- ted Whi le cum lat on t k g place it i not p s bl t e t t wheth r d ffu i simulta n ly oc r g a s the cell ystem It may be pre med how ver tl at the ame d ffu n p e t p at e und r fav rable metabol c con d t o s Wh n ti n (cent tion) f spe fi b m gr at m ide tha outs d the y t m m n e t by l ffi s o w uld l e utwardly di ted

Donnan equilibria The e te d to ar e when r a o or ha ged p ti le uch as a ll dal m c lle c mplex s n n way re t a n l i its m em nt Inte a t n f sl wly a d apidly m i g ch g d pa ticles n ol es a Don n eff ct just a if th p rt l nd n w e eparated by membr n n t ad l by a diffe e n vel t Fo ny p f a n r c t th f ll wing o c nt at r tios h uld b app o ched e t l b m b tw n i o l t t s f x m pl tw l t n pha e pa t d by an i terposed d ffe tally perm abl m mbr ne

$$\frac{[\text{An o s}]^{\,i}}{[\text{An n}]} = \frac{[\text{Cat s}]^{\,o}}{[\text{Cat o}]}$$

i wh h i nd d te pha nt l d t l t th m mb a e and A nd C d t the ale i s f th a n and t o r pe t ely Al

Table 4 D fferential accumulation of ions in two species of Halicystis

Ion	Se wat	*H oralis*	*H o l ho ll s*
	M l	M lar	Molar
Cl	0 5?	0 55	0 60
Na^+	0 50	0	0 56
K^+	0 01	0 3	0 006

D nn n r t s

H r l $(Cl^-)\frac{0\ 55}{0\ 5} \neq (N\ )\frac{0\ 50}{0\ 2}$ o $(K^+)\frac{0\ 01}{0\ 3?}$

H sl ho l $(Cl^-)\frac{0\ 60}{0\ 5} \neq (N\ )\frac{0\ 50}{0\ 56}$ o $(K\ )\frac{0\ 01}{0\ 006}$

Co np so are m de of th co ce tr t o s f th p n ipal ons between th v cuol r sap and the e n l bathing m d i m u d r natur l cond t ons

ondary roots Thus the plant progressively taps new volumes of soil and increases the acqui ition of mineral nutrient

HEREDITARY ABSORPTION POTENTIAL OF SPECIES

The hereditary potentialities of a species are predetermined by its ancestry and are fairly constant These limit and determine the internal physicochemical conditions and the extent to which proce es may proceed in plants This is exemplified in the differential movement of inorganic solute ions into and their accumulation within specific organisms Although exposed to like external conditions two distinct genetic types may exhibit different permeabilities to and net absorption level of inorganic olutes Environmental factors may alter the internal conditions and proce ses of an organism but the extent of the effect will be limited by genetic potentialities Under similar natural or experimental conditions different species vary characteristically in the extent to which certain ratios of ion accumulation de elop within them (Table 4) These levels appear to be unrelated to tho e essential to growth proces es of the organism they often represent luxury absorption or relati e exclusion of ions and may in olve types of ions not now recognized to be nece sary for development of the pecies

Cell membrane permeability The condition of permeability is important With a boundary limiting pa sage of materials inorganic solute absorption can be controlled or restricted Permeability the opposite of re istance to movement is a property of a limiting tructure or meml rane parti ularly the protopla m including the restricting surfaces there f

Several theorie ha e l een pr po ed to account for the differential permeability f living surface to penetration of olutes Accumulation of oriented molecule of lipoproteins and pho pholipids at interfaces has been propo ed Studie with relati ely nonpolar sub tance led to the lipoidal theory Thi is a olution hypothe is of permeability whi h a sumes that the penetration of different sub tances i in proportion to their solul ility in the lipoidal sub tances of the limiting surfac Th r are compound however which are lipoid soluble and yet have been found to enter living cells rather lo l To meet this objection the solution theory i n combined with the concept of ultrafiltratio through a sievelike nature of the protopla mic face In this ca e the rate of migration of a stance into a cell would be related to the ize its existing particles or ag regates the limit surface erving as an ultrafilter Mo aic tr c of the protoplasmic surface or tructural cha from time to time have al o been propo ed Ch acteristics of protoplasm as a whole or of limi surfaces such as these are no doubt invol ed in ple diffusions Donnan effects and po ible change ad orption which are discu ed in the s tion of this article on the proce s of mine al sorption Rates of penetration even for electrol such as mineral salts or their ion could be a quate if the limiting thickness is small and intensity gradient for migration great

Considering the protoplasm as a living diffe tially permeable membrane no doubt its u ual meability is also dynamic and determined by rent metabolic processes within it Permeab for all kinds of movement of mineral ions into across protoplasm are therefore controlled dy ically by the colloidal state or organization of protoplasm under any condition of metabol Protoplasmic activity also determines the accu lation of solute For metabolic ac umulatio the secretory proce s across protopla m ome of interaction bet een ions and protopla m re Thus p rmeability becomes a quantitati e con which i related to metabolism and the tate o protoplasm as a whole acro s which movemen curs This propo al of a dynami metabol controlled differential permeability of protop and mo ement into and acro s it helps to cl the concept of the hereditary ab orption pote of species Thus the rate to which pe ific ion accumulated or excluded is determined by the cific metabolic conditions in the protopla m species and is limited in extent by its hered potential The mechani m for p netrati n an tention is di cus ed in this article under meta acti ity of absorptic n cells

Interionic effects There are many interionic ef fects in the s il plant system The soil is a d namic system ions mo ing within the l ition and s luti n oil olloid pha e Within the soil solu ti n d uble de ompo iti ns occ ir as in ther m ple multisalt olutions The e change are of con equence in the mineral nutrition of plan since in general eparate ions are al rbed b root However there are continuous interchange of cati n l etween olution and il colloid W water movements supplying a changing l athing so lution f r colloid in a parti ular locale change in the ionic l alance l etween lution and c ll l can occur The ionic mak up of tl e lution can modify tl e ll id di per ion an l the pr perti f i n n tl e d per ed pl a e It can al o m d the rate of soluti n fr m tl e parent min ral th h te lution f m m l latti e i con

T bl 5 Certa gen l rel t on betwee lt absorpt on a d espiration by bs lsed barley roots

F pe m tal co d t	S lt co t t f t co trol	CO f co t l
Co trol, t 0 C	100	100
KB 0 00 M 0 C	00	1
KB 0 00 M 0 5 5 C	1 0	0
KB 0 00 M N 0 C	9	40-60
KB 0 00 M KCN 0 001 M 0 C	90	[illegible]

a m lat n di tl r and ctly m olves the t ca bo yl c a d y l the d hyd g n e fla o- p t d ytoch omes The equence r im p rt c f e h i p esently nknown Inhib tor of ox d ti e met b li m estr t m tabol ac umu l i d r b esp t o n a ma n r s m la t ffects of a bi i th ugh th tep i me- tab l m ffe ted m y d ff E hanced met boli cum l ti n f lt a oc ted w th an m ed a b esp at o at Th u h th ge al effect ac th no d re t p po ti nal ty betw en th th t tal sp ati ate r th encha ed tesp r ti n te a d the ate of m n l ab rp- t (T ble 5)

Outer or free space concept W thin ell and pl nt s a wh le th e ol t l ames in h h e dy d ff n i m te l oc r Theo- et c lly th e r adv m x g f b t s r lt ng q al ty f c nc nt t n (t t) n a pu l t E e l t on t f m me t a e lt l w dep d ng n the n e t at g d e t d th atu of th m d m th t t p rm b l ty f r m me t of a t t t Wall f ells h p t wh h w t l t n may nfilt at a film lum s a ult of p lla ty d mbib t D ff s f lte an proc d d ly f g di t p pe d f th q u h l a t m d th r d m m f q te S h soluti n pa e t med t f e p N f of ll f ll d w th l t n wo ld b d ed a l ee p Th e t m sol t p p ot pla m th qu s d p n med m mp th l n pha f th d am ll d l sy t m lt d bif l h th t thes p n p ot pl m rs p rm bl t sol tes No d bt t ami g f p t pl m pla l m n nt l m n l b ra es th p t pl m pe h p m mp t fl

B tw n e ll l m pla t t es th t ll l p h h film f sol t m m t These th mmed at b th g med f r th di d l ll f th t t Th flm m y l t n m th gh ut t es ntil t t pted th b m l d g s h l oto- pl m all d ff t t s ch Ca p t t ppe t ffect di t t b tw t th t nd f pa f oot M a m t f f ee d ff b t een ll not d xt l lut l ad t appar nt f ee pa al es Th t be d ectl q ted th

real I me be au e th part t n c effi i nt f r any lute between an xternal s l ti n and that w thin the apparent fr e pace is p l l lly not u ty Ad rpt o wl ere p lle by fi ed charge y tem nere es appar nt fre pa e alues r la ll e to true free pace Th t p t n f the l ite wh h i rbed at the wall u face i mea t ral le by o i xchang a d redu ed n g r p rti n t the d ff dilut n e r r where estimat m f appar ent f e pa e pre edes that of ad rpti e ch nge At the t ady tate the acti ity t e t nt alth ugh th c ncentrat n f a titu nt in solu ti in the films r c l mn a es with d tance fr m th otpt n urfac

Acro root th free pace e t n um app ars t be r th r effect ely i terrupted at the ndo- d rmal wall He e in large mea r ul tances m t pa th gh r acr pr t pl m Since protopl m d e t ppear t aff rd an effect ve f ee p e e nt nuum in di et c n ti n w th o t r or ner f e p ce it wo ld em that ma fl w m ement (c mpo it fl x) f luti n or ev n d ffu i s w uld be n gn fi a t radi lly ac os root Va pecies r the ame p cies unde othe gr th o d ti s (p rticularly tho wh h m ght mod fy e dodermal wall d ff r ntia t n) m y vary q a tit ti ely n th s re p ct S g nifi a t a d imp rt t m grat m nd m mpo te fl x d oc ur w thin th n e p ce of root a d atta hed h t An mpl th fl w the xyl m wh eby m e al t ie t nd wate are rap dly tr n po ted t cells a d ti e th ugh ut th pla t Th s l ds to n el t n c ment (in clud g f t s rel ted to e dati and t n p ation) f m t b li ccum l t on Salt em tted nd d ff ng i wardly w th ts r eluted a a ompo ite fl x ll w ng orresponding prop r i e m r me t of m tab l c c um lat to occ Re- lat n h p b tw en lt abs rption and tran pira ti n rat s a pr babl n d ed If m flow f s l t n does occu o t n u ly f om med e ter nal t o t and through the plant (fo example r d ally d l g t d n lly th ough t cort c l tis e) ts l k l hood d r a e pr g es ely f m fi ld ap cit t th wilti g pe t g f wat n ls

Role of carriers S lts d not acc m l t in l ap o w th n the m t c sy tem f ots u l nd ti n r u tabl f r ae b c (x da ti e) m t b l It ll upp d that uch met bol a mulat n l th f rm t on f c mpl e betw en the ons d gan titu e t n e d f th p otopl m layer foll wed by d nh n d by trean g to the ther d f the pr t pl m l y wh d so t n u s w th l a of the d fo mati n of th a r m le ul Th e m y th n m se b k the m mb n pr to t an p t of the o A mb of th o t c l mod ls h e b n oposed a d ha p rated m tro S r l f th n t l t th p es ce of pt l d n b t ces wh h act w th th c t r n xte l a d t t al l at n f p t pl m

though generally applicable ionic equilibria of this ort are not usually observable in the over all osmotic systems with living cells However the Donnan phenomenon may play a highly significant role between protopla m and the bathing media where a limiting surface is interposed or where great velocity differences of migration exi t Such effects could lead to accumulation in protoplasm In so far as metabolically produced organic radicals may be involved as the slowly moving or restrained ionic species this mode of absorption may be indirectly sensitive to inhibitors of metabolism and may be pH dependent

Ionic exchange Colloidal systems are important constituents of living tissues and the phenomenon of exchange adsorption plays a significant role in cellular physiology of inorganic solute absorption Ions are ad orbed on the surfaces of charged colloids These may be exchanged for ions of the same sign from the dispersion medium Usually the exchange is of the nature of a diffusion exchange similar to double decompo ition of molecules in solution With plant systems in which certain ions (for example hydrogen ions) may be continually produced metabolically accumulations of other similarly charged ions from external solutions by exchange are possible The concept of ionic exchange migration has been extended to include ionic movement from one colloidal micelle to another Thus the movement of ions along surfaces without intermediate passage into the dispersion medium may be effected (Fig 4) The best evidence that exchanges take place is indicated by the outward movement of pre iously absorbed potassium when roots are immersed in external olutions of other mono alent cations Approximately 10% of the potassium pre iously intimately associated with root tissues i readily exchangeable Probably root surfaces and cell walls external to the endodermis are primarily concerned The adsorption exchange is independent of direct aerobic metaboli m Similar exchanges of anion ha e been observed This uggests that although cell walls or chemical components thereof po se s an o er all negati e charge favorable for cationic exchange both negati e and po itive charges exi t here Exchange reactions are not restricted to mineral i n

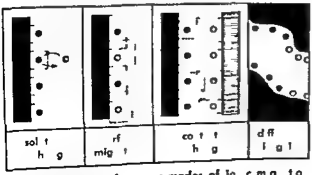


Fig 4 Diagram of va o s modes of Io c m g to espec lly ad orpt on e ch nge (F om E Tr og ed M ral N t t of Pl ts II v of W o s 1951)

of monovalent charge nor to tho e of ... charge value

Mineral ion absorption A third mode of m gration of mineral complementary to Do n phenomena and exchange ad orption may effect accumulation of mineral ions by ab orption This is called active or metabolic accumulation and is effected through the direct expenditure of m abolic energy in the protoplasm The over all m e ment across protopla m (radially acro cell or a root) is a secretory proce s Secretion in olves the eparation of ions from an external olution their passage through the living protopla m and their emission into an internal solution In contra t th other modes of movement metabolic accumula i n has a high temperature coefficient characteri tic of chemical processes and is dependent on oxidat e metabolism

Diffusion or exchange ad orption of ion m precede or follow metabolic accumulation a in tal or final steps or may proceed concurrently th metabolic accumulation provided conditions uch as activity difference are favorable Diffu ion a d exchange adsorption are probably minor in the over all movement of mineral ions into plants relative to metabolic accumulation Metabolic mo e ment into and acro s protoplasm is rapid and therefore requires either a high effective permeabil ty of the protoplasm or a large effecti e energy intensity gradient through protopla m or both It has been proposed that the sub tance chelates or combines chemically with or is orbed on a con titue t of the ectoplasm as a complex It i till a moot question whether an ectopla mic membrane or in terface controls initial entry through micropores The same problem though modified due to different conditions is posed for final movement acro the endoplasmic membranes or interfaces into internal aqueous phases such as vacuole Within ect plasm there occur some ort of cytopla mic interaction or as ociation with the sub tance migrat g Pa age through the protopla m from ectopla m t endopla m may be either by exchanges on metabolically graded complexes or complex m e ment (carriers) Transfer by the latter would be effected through di turbance of the tability of the complex gradientwi e with the re ult that the ... protopla m a ociati n is sub equently broken and the substance relea ed (emitted) to internal aqueous pl a e Complex formation appears plau ible and wo ld occur gradientwi e t ward outer protopla mic ite at which the energy level of the ub tance being metabolically ab orbed would be reduced Gradientwi e toward inner prot pla mic ite where the po tulated complex is di sociated due to in tal ility and the sul tance relea ed th con tituent gains er all free energy in accord with it acti ity incr in sol iti n At thi stage the ffecti e ncentrati n (acti ity) of min ral io is greate t The energy tran fer i effected fr m metabolic rea ti n within protopla m m diat d thr ugh the gly lysis cycle (s e PLANT RESPIRATION) The metal s ciate l with n

ga ic s l t dep nde t n the supply of q t am nts nd type f b t ate fo x d m t bol m S g r pply is pa t la ly im rta t he e U ually co d ti n f l w salt tr t d h gh u r s pply r o r ely gh alt a d l w suga r n p r ll l n r ot

Pe m abil ty a d m t b lism Th e f t lt r tes d ff e c the extent of metabol c a m l ti Perm b l ty ffect the r t s of each nd all the m de of m grat o of m e al n t ents The m t b li m fa to perm abil ty ca n t s p ated fr m t xp rime t lly Th y m tely e ted met b l m of the p t pl sm determ g n la g m a e p rme b l ty modified d ectly t le e te t by oth r f c wh h l d t rm e th m t bol m The e evid e wh h gge t th t m t b l c ab pt n f m l s t m tely l ked with p ote syn th s the c p ty of ells r t es fo fu the gro th d dev l pm t (F g 5) M r temat c ll are p rt c larly a ti e ti d a m l ti f lts wh le m t d n ce t ll ea be l m y eve bee me d plet d f p o mi l c tent th ugh r tr l at Pro ded e gy ten ty diff ce p p a d mod of t port e t, the m er l n t nt m y m w th th pl t t a t pabl of cell d s r c t d g wth d de l pm t Th d the po ble a d effect l t s re d b t ble

Translocation of mineral compounds S lts m lated by abso b g ell o g m to t rm l tes Va u l of b b g ell re ne h loc t S l te m y mo e th gh p oto- pl sm byp g t rmed te l o thr gh w ll t i te l f e ol t n pa e uch t l es l a d b t l c ted t term d t d t l fo m l ti by ell Wh lt m b l t l t on f m t m l te t th r tern l p t n m y oc r Th m j p thw y f apid pw d m me t in th t n sp t t p e u e tre m th l t ar g th th gh m s f m th p t pl m of ll w th th t l The e m er l tri t l ted d m d mp st fl (m fl w) l g th t ll b d i g the ylem l g the w y d t th ll f t rmi l g Oth m m f mp m l (t) p st n f oot t m d t l ( ) p t by d ff d po bly by m me t th phl m Som e p m t l d t gg t l m ted pw d m me t th gh th phl m Lat l m m t m y b p t l ly fl t th gh yl m (wood) y F m th — yl m t les t t phl m—th m t the ll f th t by m g t th p m ry b rpt

A m g th q t t t ly d q t p f m l t t th e t l med m a d th m b l ty (fi ed d t th n h mpl t m l) b rp- t t oot a d t l t th gh pl t lly d ly ff ted f ll th ece ary le- ment G lly d fi y ympt m wth

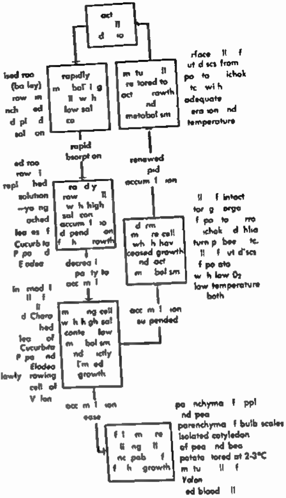


Fig 5 Sh m t l t h p m g tat typ f pl t t d ll w th g d to th l b l ty t m l t l g l t (F m E T g ed M l N t t f Pl t fl F W 1951)

eta d t a e t ob rved w th fa orable pply th m a s f m me t be g uffic e t to ff d t dequ t fo m m l gr wth a d dev l p- me t H we e mob lity the med m f te deq t th gh lub l t e fi t e t l i n e c mp t t l t m e n b lan t lly may l m t p m b l ty fo b pti n a d th s le d t defic y f ele- m t fo wth

Redistribution of minerals A ed st but n of m e l s effect d th o gh t l t n that wh ubst m ut of a t rm n l loc g t s m th p rt f the plant Th s, f ampl m l may m f m lde t y ge l f om l t ther c ll R t l t n f m t rm al te depe d o the b l ty f th ll a ted w th s ch t t t th lt o t t d th m b l ty of th Th r t t n d p ds o th m t b l t tu f a m l t n t the s te wh s h b l ty d es w th m t g t c ll o wh n lt m m t byp l i ympla m m t the t R t loc t n i ge

thus effecting supply and removal of carrier for the complexing and decomplexing steps of protoplasmic interaction with mineral nutrients. According to one theory, a polymerization and depolymerization of the carrier occur. All theories rely in some measure on diffusion of the carrier complex through protoplasm. Absorption of cation ion models suggest progressive exchange adsorption along surfaces, not necessarily requiring that the carrier itself move in space. The nature of the carrier is a moot question. The phosphorylation system has been suggested specifically for phosphate. Protein as carrier, involving their amphoteric nature and possible unfolding and folding for association (secretion separation and elaboration) and dissociation (secretion emission) respectively, have been proposed. Ribonucleoprotein has been considered whereby the nucleic acid portion could "bind" cations and the protein anions.

FACTORS AFFECTING MINERAL NUTRITION

External factors and internal controlling conditions influence rate and extent of solute absorption. Of the external conditions, aeration, temperature, and the supply of water and mineral salts are important. These conditions may alter and determine the internal physicochemical conditions and the relative rates of processes some interrelated with absorption.

Aerobic environment. Such a condition is essential for metabolic accumulation of mineral ions by plants. In cultures, reduced accumulation becomes apparent when the oxygen concentration in the solution is less than 3–5%. A fairly close correlation exists between these effects of oxygen supply on accumulation and respiration, increase by comparable ratios. Probably the permeability to entry as well as the oxidative metabolic processes concerned with the accumulation are affected. Efflux under anaerobic conditions is protracted.

Temperature. Temperature of the environment is a second factor which may influence the rates of physicochemical processes. Increase of temperature is usually associated with an increase in the rate of metabolic accumulation and in the rate of aerobic respiration. Metabolic accumulation has a high temperature coefficient (2 or above), especially in lower temperature ranges. From the concordance of temperature effects on accumulation and respiration (especially the respiration increase), some interrelation may be inferred between them. The other modes of migration or possible composite flux of minerals are characterized by low temperature coefficients. As with anaerobiosis, at low temperatures any efflux losses are slow and protracted.

Water supply. The influence of water supply in absorption is indirect. Salt and water migration are independent processes though interrelated in so far as movement of one of the components can alter or determine migration of the other. The movement of water into tissues will dilute the concentration of salts within the system and lower the accumulation level therein. Rapid water absorption and transpiration will tend to remove salt from internal sinks, further lowering the accumulation level. Since metabolic accumulation can attain limited characteristic maximum levels, dilution or removal from within cells will allow continued enhanced accumulation. Since absorption is primarily accomplished as ions, water is essential to the dissociation of the constituent salt.

Supply of mineral salts. The condition is axiomatic. Furthermore, the concentration and relative proportion of mineral ions may alter or control inner processes. The rates of accumulation and respiration are enhanced, generally logarithmically, though not necessarily proportionally, with increasing concentration of salt supply. Interionic effects were discussed previously in this article. Varying concentration changes modify these effects. The relative rates of anion and cation accumulation may be similar or distinctly different. Excess accumulation of cations over anions is attended by an increased concentration of tricarboxylic acids, especially malic acid, offsetting the ion absorption difference. Conversely, a decrease of such acids occurs with excess anion absorption. A monovalent ion usually accumulates more rapidly than a divalent or polyvalent ion. Absorption of a particular ion is influenced by the presence and concentration of other ions, whether of similar or different charge or valence. Relative rates of migration among ions are no doubt modified by the relative importance of the various modes of movement in a particular case. Interionic effects are not restricted to competitive effects mutually reducing absorption of ions. Under appropriate conditions the presence of certain ions may lead to increased inward migration of others; however, this effect is not observable under conditions which inhibit oxidative metabolism. The hydrogen ion concentration of the medium (pH) can influence absorption. Over the range pH 4–8 such effects are small in culture solutions simulating soil solutions; the relative absorption of cations to anions is such as to bring the medium toward neutrality, that is, on the acid side anions tend to be absorbed more rapidly, on the alkaline side the converse tendency exists.

Hereditary limitations. Conditions within the plant influence absorption rates or levels. These are hereditary limitations which through permeabilities or metabolism control the balance and extent of mineral accretion. Characteristically certain species are selectively calciferous or siliceous, or high in sodium.

Previous history of tissues. The previous history of tissues will influence subsequent absorption of salt. Prior salt content is a factor. Physiologically high-salt plants may not acquire more salt except as growth dilutes their salt content, allowing further acquisition. Roots high in salt can absorb more, provided that some of that which is emptied in the secretory process is eluted and transported to other parts of the plant, as with the transpiration or exudation stream. C... accumulat...

of n ga lute is depe d t n the upply of adeq at m u t ard typ f b t te f r da t e metab l m. Su a upply s p rt c l ly m portant he e U u lly d t n of low salt con nt atı n a d h gh g upply r o er ely h gh alt a d low gar par llel n ts

Perm bil ty a d m t b li m These fa t rs alte th rat s nd ı fl en the e t t of met bol c a umulati Perm ab l ty ff ct the r tes f e ch and all the mode of m g tıo f miner l nut e t Where metab l m ı a fa to pe me b l ty cann t be ep ated from ıt xp rıme t ll They a e ı tımately onnected metabol m of th otopl m d term ng ı large measur t permeal il ty m d fied d ectly to a le e extent b th r fac tor h ch ls d term th m t bol m The e ıs vid ce whi h ts th t m t bol ab orptı n of m n al s t mately l nked w th p otein y thes r th p c ty of c lls r tı n f r fu th r gr wth d de el pme t (F) Me t mat ll a part ula ly cu ı o t nu d a mul t n f salts wh le m t e a d s s nt ell can b l s may e e bec me depl ted f p ı m l nt nt tht gh r t an lo at o Pr ıded ergy nte ty d ff ences a pr per nd mod s f t port xist, these m ner l t ent may mo e w th the plant t ıt p ble f cell d o t n ed g wth d de el pme t These a d th sibl aus a d ffe t rel t o s a d bat hl

Translocation of mineral compounds Salt a um lated by ab rb g cell or g ns m e t term al tes V cu les f bsorbıng cell are ne u l l ation Solute may mo th gh p to- pl m bypa s ng interm d at ole thr ugh wall ı to t m l f e a l ıt o pa ch s t l s l d b t n lo ated to ntermedı te d t l r gıo s fo m l t n by ell Wher alt s m bil tr l t on f om t rmı al te to th nt n l p t m y cur Th majo p thw y f r ap d pw d m em t ın the tr n p t n oot pres e t am th lut s rn ng th e th o gh em s o f m the otopla m of ll w th n th tel Th m n al n t nts r l t d a d m d a a mp s te fl (n s fl w) l g th e t ll l d rıng th ylem l ng the w y nd t th ll f t m l Oth m y mo f m p m l t te l p s t of root to m d tal (er) p t s by d ff ı n nd pos bl by m me t th phl m Some xp rı m nt l d r ggest l m t d pw rd m em t th o gh the phl m Late al mov ment may b p t ul rly ffects th ugh yl m (wo d) ay F m the —xyl m r to le se te t phloem—th o m t th ll f ther t s by m g t n a n th p m y b o pl

A m g the q t t ı ly deq te p f m al t ı th e t l med m d th m l l t (n fi ed nd t n th m n ex h g mple a pa t m n l) absorp- t t oot d t a l t thr ugh pl t ı lly ad ly ffected for ll the eces ary l m t G lly d fi cy ymptom o gr wth

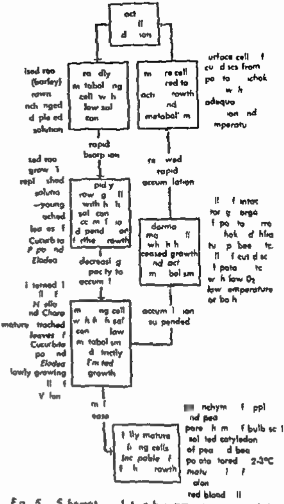


Fig 5 S hemat l t n h p am g p t t v typ s f pl t t u d ll w th g d t the b l ty t m lat g ol t s (F m E T g ed M f Nut d f Pl t U f W P ss 1951)

ta d tı n r n t obser ed w th fa r ble upply th m n f m ement b g s ffic e t to affo d r t s adeq te f m ımal owth a d devel p- ment Howe e ı c m b l ty n the m d um ıs of ten ınadequ t th ugh ı lub l t r f at ons or e t l o mpet t n In e t eme ca es n bal n es t rnally may l m t p rm abil ty fo b pt n d thus lead d ficıen y of an ele me t f r gr wth

Redistribution of minerals A d t ıl utı n f mı e al ı effected through etr sl t n that wh n ub t n m e out f a termı l l a tı n o o g ı t s m the p t of th pl nt Th s f mple mıne al m y mo f m lde t young r lea es fr m c l s to other ells

Ret sloc t n f m t m n l t dep d o the b l ty f th lls s ı t d w th ch t t r ta th s lt ntent d the m b l ty f th ns. The r t nt n d pe d th met b l t tu f c um l t t th t when ch b l ty de- c ea es with m tu ng r e nt ell m s lt c mov t th tes Retr l c t n g

erally a diffusion from higher to lower concentrations (activities) except where modified by streaming movements and transpiration water utilization or metabolic accumulations at secondary terminal sites. With dilute soil solution low concentration of mineral nutrients reach terminal leaf site through flux in part in the transpiration stream much is absorbed by cells along the way. Excesses over those thus accumulated or used in growth processes move into pathways where they are retranslocated in a downward direction principally in the phloem along with products of photosynthesis. Here diffusion modified by streaming may occur where gradients are proper. Some experimental data support the hypothesis that mass flows occur through sieve tubes in the phloem activated osmotically in a manner similar to exudation in xylem but not directly interconnected therewith. Thus there is a general circulation of mineral nutrients with intermediate cellular absorption or utilization. Progressive translocation and retranslocation of mineral nutrients causes a changing pattern of solute distribution in plants. See FERTILIZING; HYDROPONICS; PLANT MINERALS ESSENTIAL TO. [T C B]

Bibliography: C. Ellis, M. W. Swaney and T. Eastwood, *Soilless Growth of Plants*, 2d ed., 1947; D. R. Hoagland, *Lectures on the Inorganic Nutrition of Plants*, 1944; C. A. Lamb, O. G. Bentley and J. M. Beattie (eds.), *Trace Elements*, 1958; B. S. Meyer and D. B. Anderson, *Plant Physiology*, 2d ed., 1952; E. J. Russell, *Soil Conditions and Plant Growth*, 8th ed., 1950; B. T. Shaw (ed.), *Soil Physical Conditions and Plant Growth*, 1952; E. Truog (ed.), *Mineral Nutrition of Plants*, 1951.

Plant, minerals essential to

There are 16 chemical elements recognized as essential for the growth of higher plants. Soil minerals supply 13 elements (excluding carbon, hydrogen and oxygen which are obtained by plants from water or from atmospheric gases). Six of these elements are called macronutrients because they are required by plants in relatively large amounts. Nitrogen, potassium, calcium, magnesium, sulfur and phosphorus are needed in the order listed. The micronutrients required in small to minute quantities are chlorine, boron, manganese, iron, zinc, copper and molybdenum. With the exception of chlorine, deficiencies of each of these have been shown to prevail under certain agricultural conditions. Further research may disclose that other elements are also essential for higher plants. Experimental evidence indicates that vanadium is essential for growth of the green alga *Scenedesmus obliquus*, cobalt for blue-green algae, and sodium for blue-green algae and the seed plant orach (*Atriplex vesicaria*).

The presence of elements in plants, however, is not proof of their essentiality. It has been proposed that an element not be considered essential unless (1) a deficiency of it makes it impossible for the plant to complete its life cycle, (2) such deficiency is specific to the element in question, and can be prevented or corrected only by supplying this element, and (3) the element is directly involved in the nutrition of the plant apart from its possible effects in correcting some unfavorable microbiological or chemical condition in the soil or other culture medium.

Approximate critical concentration levels of essential mineral elements in higher land plants

Element	Dry wt, ppm
Macronutrients	
Nitrogen, N (total)	1 000
Potassium (sodium ...), K (N < 15 000 ppm)	[illegible]000
Potassium (sodium ...), K (N > 1[illegible] 000 ppm)	10 000
Nitrate nitrogen, NO_3-N	1 000
Calcium, Ca	[illegible]000–3 000
Magnesium, Mg	1 000–[illegible]000
Phosphate phosphorus, PO_4-P (total)	1 100
Sulfur, S (total)	[illegible]000
Inorganic phosphate phosphorus, PO_4-P (... g ...)	[illegible]0
Sulfate sulfur, SO_4-S (inorganic)	500
Micronutrients	
Chlorine, Cl	100
Boron, B	[illegible]0
Zinc, Zn	10–[illegible]
Iron, Fe	10
Manganese, Mn	10–[illegible]0
Copper, Cu	3 10
Molybdenum, Mo	0 –0 [illegible]

Diagnosis. Measurement of the concentration of particular elements in plants or in available form in soils can be used to diagnose the adequacy of supply. Diagnostic techniques with soil minerals indicate the amounts available for plants. Plant analyses and correlated growth indicate what mineral status the plants have been able to acquire from a soil and the development attained with these minerals. Approximate critical concentrations have been ascertained for plant tissue below which a reduction in growth might be expected.

Utilization of minerals in plants. Utilization, in contrast with absorption, refers to the incorporation of mineral elements into the constituents of cell wall and protoplasm or to their direct participation in metabolic reactions. Mineral salts may be absorbed and not utilized. Some may remain indefinitely in the ionic state in cells; many are incorporated into more complex but unassimilated molecules. Minerals utilized in one organ may be subsequently released, translocated to other plant parts and reutilized.

There are several general functions of mineral nutrients in plants. Some may become permanent constituents of molecules which are integral parts of protoplasm or cell walls. Examples are sulfur and nitrogen in proteins, phosphorus in nucleoproteins and lecithin, magnesium in chlorophyll and calcium in calcium pectate. Some mineral elements are constituents of catalytic systems. Of these, some may be constituents of certain enzymes whereas others may act as activators or in

r f n o m r enzym ystem I on op nd z c ar k own to be c t tne t f ce nzymes M gne m and mangan ■ act as t s hibit rs ■ nzyme syst m

I ut i nt may I aff t th p rme b l of p t pl mic m mbra The perme b lity r t pl m is nflu nc d by both n a d at M n le t at ons ge e ally r a pe b l ty f p t pl m D ale t d p lyv le t s ■ ally ed e perme l l ty f ■ to- m th pr m ry ffect s ally s f llowed in by a c ndary ■ a g eff ct o p rmeabil e pec ally wh m oval t a o s ■ pres- A i g ne lly i re perme b lity t v le t at ■ If the val y f the an n e I th t f the at n n r e perm b l es lt f th e s tru th in t al ffe t d re in permeab lity f ll wed by a ■ ond e N t ly s th perme b l ty of p oto m t m ral lt fi e d by o b t p tio f the phy l g al m cha sm f a e m n s l fi ed by sp fi io s ntact h the ll All of the m c n tre t i m d th e met b l cally p d ced a e o n d i these eff t L ttle k wn exp me ly n thi g d b t th m ut nt on e l lt may i fl en e the m t p e pl nt ells th r m ti yst m The p m t pl nt cell i l w n cent ati n f m eral alts and nly m ll prop rt on of the os motic p es u e f cell sap can be a ribe l t ch c mpou d becau e suga and oth r lute ar p e t. However there a e notable ex epti ns uch s alt if m s pecie in which the accumu l ti n f od um a d chl r de ion i ery high M ne al nut ie t n such s ph phate may play a le n cid ty n buff r act n in plant Meta b l ally g ■ ated hydrogen ion and o a e a io s are also tegral mp ents of plant l uffer sy tem Cat n e mpon nt of plant b ff yst m re mo tly pot um cal ium and magn s m

M e al lem nt m y ex t ■ tagoni tic or mpetit e eff t O e n r s lt may ff et e n ■ th al ffe t of nother n alt A rea nal l phys log al bala i nece a y in the med um and in the *plant* A*bno mal ratio* may lead to deranged perm ab l ty a d metabolic pro e ates Calc m play p min t r le in e t bl h g f v rabl pr t pl m rg *zation* Some elem nt altho gh esse t al i limited m u ts m y p o t e at highe level The e clude ot o ly el ment r c g zed to be n es ry f r growth but al o m ny n t c n idered Th mo t x element in lude al m n m b ron ppe magn m molybde m a d c

I dd ti n c tain p ific roles of m neral nu t ient may be ted N trog a comp n nt of n ds nd pr t i which c n titute the b

Symp m f m l l m t d f h wn m g m (7) bo (8) lf (9) m g by tob pl ts Th d f t l m t (1) t o- (10) All th l m t w ppl d t (6) g (2) ph ph (3) p t m (4) l m (5) (USDA)

sub tance of protoplasm Sulfur is al o a constituent of amino acid and proteins and of thiamin and biotin which are ■ ential hormones in plant Phosphorus as phosphate enter into the composition of pho pholipids and of nucleic acids the latter of which combine with proteins forming nucleoprotein Phosphorus al (plays a key role in the transfer of energy through phosphate l onds in metabolic proce es Specific roles of pota sium remain obscure however it appears that potassium i involved in ome way in the synthe is of proteins from amino acids and in carbohydrate metabolism Calcium i a con tituent of the pectic compounds of the middle lamellae of cell walls it appears to be involved in nitrogen metabolism and ■ plays a unique role in maintenance of protopla mic stability or favorable organization in permeability relations and metabolism Magnesium is a constituent of the chlorophyll molecule es ential to photosynthesis it plays a role in phosphate metabolism or the respiratory mechanism and magnesium ions appear to be specific acti ators of certain plant enzyme Iron is e ential to the synthesis of chlorophyll it is al o a constituent of ome enzymes and carriers which operate in the respiratory mechani m Boron appears to play a role in protein synthesis and po sil ly in sugar transport however its exact role is unknown Mangane e is involved in oxidation reduction phenomena with iron it ■ al o an activator of ome enzyme sy tems Zinc is a constituent of the enzyme carbonic anhydrase howe er its role in metabolism of plants is obscure It appears to be necessary for the synthesis of the growth hormone indoleacetic acid Copper ■ a constituent of certain oxidation reduction enzymes Molybdenum plays a part in the reduction of nitrate The role of chlorine is unknown though it may be necessary to photosynthetic activity

Mineral deficiency symptoms in plants Inadequate amounts or unavailability of any of the e ential mineral nutrients in the oil or other medium in which roots of plants are cultured may lead to decrea ed growth and isible defic ency symptoms Such changes in appea ance may al o occur when the element ■ present in the tissue if for some reason it ■ unavailable within the plant or cannot be utilized in metaboli m Thus on may become immobilized under certain cond t ons and iron deficiency may become apparent e en in plants contai ing c nsiderable ron Symptom of the deficiency of a certain element are imilar in different species though the manife tations may vary in some a pects from species to spec es Deficiency symptoms may be grouped into key and arranged according to general char cteristics such as the age of the organ or tissue affected as chloroses or other color aberrations or as ne ro e Occasionally under natural condition modified ■ymptoms may develop when more than a i gle deficiency is in olved *See* FFRTILIZER FERTILIZING HYDROPONICS PLANT WATFR RELATIONS OF

[T C B]

Bibliography *See* PLANT MINERAL NUTRITION OF

Plant water relations of

Water is the most abundant con tituent of all physiologically active plant cells Leaves for example have water contents which lie mo tly within a range of 55–85% of their fre h weight Other relatively succulent parts of plants contain approxima l the same proportion of water and even uch largely nonliving tissues as wood may be 30–60 water on a fresh weight basis The mallest water contents in living parts of plants occur mostl ■ dormant structures such as mature seed and spores The great bulk of the water in any plant con titutes a unit system This water is not ■ a static condition Rather it is part of a hydrodynamic sy tem which in terre trial plants invol es absorption of water from the oil its tran location throughout the plant and its loss to the en iron ment principally in the process known ■ tran p ration

Cellular water relations The typical mature vacuolate plant cell constitutes a tiny o m tic sy tem and this idea ■ central to any concept of cell lar water dynamics Although the cell walls of most living plant cells are quite freely permeable to water and olute the cytoplasmic layer that lines the cell wall is more permeable to ome substances than to others This property of differential permeability appears to reside principally in the layer ■ cytoplasm adjacent to the cell wall (pla ma membrane or pla malemma) and in the layer in contact with the vacuole (vacuolar membrane or t no plast) This cytoplasmic sy tem of membranes i usually relatively permeable to water to di l ed gases and to certain dissol ed organic compon nt It is often much le s permeable to sugars and mineral alts The permeability of the cytopla m (memb ane is quite variable howe er and und■ certain metabolic conditions olutes that ordinaril penetrate through these membranes lowly or not at all may pass into or out of cells rapidly *See* CELL (BIOLOGICAL)

O motic p e su e and turgo pressure If a plant cell in a flacc d condition—one in which the cel ap ■ erts no pres ure again t the encompa n cytoplasm and ell wall—is immer ed in pure water inward osmosis of water into the cell ap oc cur O mos s may be defined as the diffu on of ol ent molecule usually water acro s a mem b ane that is mo ■ permeable to the ol ent than t solutes d ol ed n it The dr ng force in o m i as n other d ffusion phenomena is the diffu i r p e ure (DP) of the diffu ing m lec ile in thi ca ■ the wate m lecules In ard o mo i of ater takes place unde the e o d t s becat e the dif fusion p e su e of the wate in the cell ap i le than that of th irr unding pu ■ water by the am unt of its o m tic pre ure (OP) If the o m t ■ e sur f the water n the c ll sap is 15 atmo phe es (atm) the diffu i n p e ure of the water in the cell p is 15 atm l th n th t of pure ater at the am temper ture and under the ame pre e The le r diffu on the water in the cell ap result of

he g in n wat r by the cell r lts n th exe ti n f tu g pess r (TP) ag i st the p otopla n h h n tu i tr nsm tt d t the c ll wall This es l o pr l th ough ut the a s of olu with n the c ll If the c ll wall i ela tic ome pa s o n the l me f th ell o cu s alth gh m ny k ds f c lls thi i elati ely mall Becau e f th lut m a bly pr s nt th ll ap p e es motı pr sure The o mot es ure of m t pl t cell aps l with n a 5 to 0 atm g f m gnut des alth ugh lue a h as 200 at h be n f nd in me hal phytes (pl nts th t an tole ate h gh lute m d a) Th mot c pr es f the ll f g v n pla t t sue ary con ide ably ith en ir nm ntal ond ti and nt m tab li ett t es Mo e o les reg la da ly easo l a i t n cu in th m gn tude of c ll ap m tic press res n th cell of m ny t s It i the m tc p e f th ell upled w th th d ff r ntial p rme b l ty of the yt pla m c membra es and th el ti e ela t city of th ell w lls wh h p m ts the d el p m t of th m r le tu gid cond t on cha a ter t c of mo t pl t ell

With e t ed m s f wat r nto the ell it t g p e dually ne a e unt l t equ l to th f lo moti p e u of the cell sap Subjec t n of the w t r i the c ll ap to p s e i cr a ts d ffu n p ur l y th amo nt f the mpo ed p e ure In the ample g n abo e d s r g d g the u ually mall mou t f ap d) tion a ult f ll expan n the d ffu n pre u of the t n th c ll sap d d 15 tm be f th p of sol te (the o r otic pre u e s the d x f tl s l we ng of diff pr u e) d a ed 15 atm a a re ult of t rgo pr e hen ma mum t go s a hed He h dyn m eq l b m s att ed th d ff p u f th w t i the c ll ap s q l t that f th u d ng wate e nd ti n wh ch m t n e sarily bta n f n q librum i t a h ed

If th m ll a ff d d t n s mme ed olut n th n o m ti pr n f 6 tm n w d m oc r b t t d t nt a l g a whe th ll i mm e l wat D g d ng p d l ti a d me eq l b m ll be ed nd thes e m tin wh n th tu g pr f the ll ap h r hed 9 atm b t th p nt th d ff i n pr u e of th wa th ll ap a d n th n d g sol t ll b q l 5 th d ff i a p f the t r tl ll p w g ally d m n h d 15 tm bec se f th p se f s l t s a d th n r d 9 tm b a e f tu g p u e th t d t d p u tl ef i 6 tm wh h th m the d t of d ff o p t n the s r nd ng l t At dynam q l b m the n mbe of t m l l t ng th ll s d th mbe l g t pe unt f t me w ll be q l

D ff p d f ri A th mples g n d t th ffect ph l qu nt ty t ll g f ect of m me t f w t f m

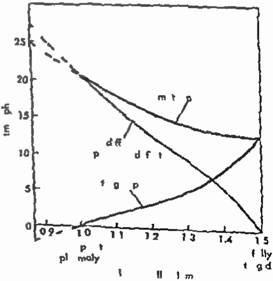
c ll to c ll n plant bet een cell and an ex te n l oluti n i the d ffu n p e re d ficit (DPD) f the water Th s qu nt ty is eq al to the o m t c p ess e of the w t r le the t rg pres- ur t whi h it i subje ted U de ce tain circum stances th turgor pre ure may be negat e in al e that s the water may b der ten on Ex amples of th ecurrence of water under te ion in pla t w ll l e d c i ed l ter in thi arti le When water i under tens n t diffu i n p e ure defic t i equal to it o m tic p e sure plus the ten ion to wh ch it i ubjected In an unconfin d s l t on the d ffus n pres u e defi it i equal t its moti p e u e si ce there s no tu gor pre re In a f lly tu g d plant ll the d ffu n pre r defic t i ze o and the tu g r p es u e s equal to the os mot c p es ure n a fully flaccid ell the tu g r pres u e s o and th d ffus on pre ure is equal t the *mot pre ure*

The int rrelat on h p am ng th pri c pal os m t c qua t ties f a plant cell can be expres ed n the simple equat

$$DPD = OP - TP$$

The e r lat o h ps a e l llu tr ted diagram matically n F g l wh h allowan e l s al o been mad for the effe t f vol m cha ge which re h act tic f ome kinds of ell w th hifts n tu go p ss re The cond ti ns wh ch wo ld pre- a l n the ell f the cell ap p e l into a tate of t n (negat p e u e) are ind cat d by the d tted exten on of the c rve to th left

Cell t ell m vement f wat in pla ts alw ys o c f m the c ll of le to the ell f great d ffu i n p es re defi it Such mo em nt of wat r in p a t t su appa ently oft n u ver con de able d t ces l ng d ff n p su e defi t grad nt wh l th d ffu n p e s re d fi it f



Fg l l t i s h p m g ot c p ssu t g p d ff p defi t a d m f a pl t ll (F m K H P & B t B t 38 288–298 1920)

each cell in a series is greater than that of the preceding one

Plasmolysis If a turgid or partially turgid plant cell is immersed in a solution with a greater osmotic pressure than the cell sap a gradual shrinkage in the volume of the cell ensues the shrinkage may be small or large depending upon the kind of cell and its initial degree of turgidity When the lower limit of cell wall elasticity is reached the protoplasmic layer begins to recede from the inner surface of the cell wall as a result of the continued loss of water from the cell sap Retreat of the protoplasm from the cell often continues until it has shrunk towards the center of the cell the space between the protoplasm and the cell wall becoming occupied by the bathing solution This phenomenon is called plasmolysis If a cell is immersed in a solution with an osmotic pressure which just slightly exceeds that of the cell sap withdrawal of the protoplasm from the cell wall should be just barely initiated The stage of plasmolysis shown in Fig 1 is called incipient plasmolysis and it is the basis for one of the commonly used methods of measuring the osmotic pressure of plant cell

Imbibition In some kinds of plant cell movement of water occurs principally by the process of imbibition rather than osmosis The swelling of dry seeds when immersed in water is a familiar example of this process Imbibition like osmosis is basically a diffusion process and occurs because of the greater diffusion pressure deficit of the water in the imbibant as compared with the diffusion pressure deficit of the water in some contiguous part of the system An equilibrium is reached only when the diffusion pressure deficit of the water in the two parts of the system has attained the same value The diffusion pressure deficit of the water in a dry seed is extremely high being equal in value to its so called imbibition pressure that of pure water is zero hence movement of water into the seed occurs Even if the seeds are immersed in a solution of considerable osmotic pressure which in an unconfined solution is an index of its diffusion pressure deficit imbibition occurs However if the osmotic pressure of the solution is high enough (of the order of 1000 atm) the seed will not gain water from the solution and may even lose a little to the solution In other words if the diffusion pressure deficit of the solution is high enough imbibition does not occur

However a difference in diffusion pressure deficits between the liquid in an imbibant and in the surrounding or adjacent medium is not the only condition which must be fulfilled if imbibition is to occur Seeds swell readily when immersed in water but not when immersed in ether or other organic liquid Contrariwise rubber does not imbibe water but does imbibe measurable quantities of ether and other organic liquids Certain specific attractive forces between the molecules of the imbibant and the imbibed liquid are therefore also a requisite for the occurrence of imbibition

In an imbibitional system the imbibition pressure (IP) of the imbibant is the analogue of the osmotic pressure in an osmotic system hence in such a system

$$DPD = IP - TP$$

The imbibition pressure may be regarded as the index of the reduction in diffusion pressure in an imbibant insofar as this results from attraction between the molecules of the imbibant and water molecules For an unconfined imbibant which is immersed in water the diffusion pressure deficit is essentially equal to the imbibition pressure since there is no turgor pressure factor The more nearly saturated such an imbibant becomes the smaller its imbibition pressure and hence also its diffusion pressure deficit A fully saturated imbibant has zero imbibition pressure and a zero diffusion pressure deficit

The stomatal mechanism Various gases diffuse into and out of physiologically active plants The gases of greatest physiological significance are carbon dioxide which diffuses into the plant during photosynthesis and is lost from the plant in respiration oxygen which diffuses in during respiration and is lost during photosynthesis and water vapor which is lost in the process of transpiration The great bulk of the gaseous exchange between plant and its environment occurs through tiny pores in the epidermis called stomates (*see* EPIDERMIS (PLANT)) Although stomates occur on many aerial parts of plants they are most characteristic of ... occur in greatest abundance in leaves *See* L... (BOTANY)

Each stomate or stoma (plural stomates or stomata) consists of a minute elliptical pore surrounded by two distinctly shaped epidermal cells called guard cells Stomates are sometimes open and sometimes closed when closed all gaseous exchange between a plant and its environment is greatly retarded The size of a fully open stomate differs greatly from one species of plant to another Among the largest known are those of the wandering Jew (*Zebrina pendula*) whose axial dimensions average 31 by 12 microns (μ) In most species stomates are much smaller but all of them are portals of egress so ingress which are enormous relative to the size of the gas molecules that diffuse through them The number of stomates per square centimeter of leaf surface ranges from a few thousand in some species to over a hundred thousand in others In many species of plants stomates are present in both the upper and lower epidermis usually being more abundant in the lower In many species especially of woody plants they are present only in the lower epidermis In floating leaved aquatic species stomates occur only in the upper epidermis

Rates of transpiration (loss of water vapor) from leaves of the expanded type often are ... or even more of the rate of evaporation from a water surface of equal area under the same environmental conditions Loss of water vapor from leaves may occur at such relatively high rates despite the fact that the aggregate ... fully open stomates is only 1–3 ...

s gn fica t the fact that the ate f diff n f c rbo d x d e t l s ph t synth esi int the l a e th gh the st mates much g at than th gh the q i ale t are of n ff cent a b n di x d ab o b ng u f c

Alth u h me m ff w of g nd btedly oc u s th o gh th t mates u de e tai o d t mo t m m t (ga e nt r out f a l af tak pla e by d ff o th gh the st mates D f f i n s t phy i al p s wher by m le ul of a g mo e fr m a reg f th i gt t r d ff n pre e to th e n of the r le e d ff s on pressure r lt of the wn k netic ct ty M lecule f l qu d and ol d (t l m ted t t) molec les nd o s f l te a d c ll dal part l l d ff wh n r th app opr te i c m t nce pre il A p o ly p nt d t mo nd mb b t n are b i ally d ff n pr ce es i ol g the m vement f mol cule i the l qu d st t

D ff n of ga e throu h m ll p s f llows ce ta p n ples wh ch ac o nt f th h h d ffu e c p c ty f th t m tes I the d ffu on f a gas th u h a mall p e verwh lm g p p t n f *the mol c les* e p n the m f the pore l t to th e p g thr ugh its e te ll c d ffu i t s th gh sm ll ape t s ry th per m te rath th n the a *The* le th a e f p th ef r th g e t ll diff v apa ty el ti to ta a Th r f e g may d ff ly s r p dly thr ugh a pt m p r ed w th numb r f sm ll fi wh e g g g t are pr ts ly m ll p po ti n f th pt m ea th gh p n *rfa e* equ l t a e t th pt m Th h gh d ff p ty f th t mat n be o nted f te m f th e p n ple S c diffu n f g e th ugh tom te pt p rt l t th *ye met* f the po th th n to ts ar a th *d ff* s n t th gh a pa t lly pe t m t alm st great th gh a fully op t m t

In g al tom t a op n th day t me nd l ed at ght altho gh th a m ny pt ns t th t t m t *The me h n* m wh f y tom te n i th l ght d l e n th da k m t b pr ipally a m t alth gh the f to a e pr b bly in ol ed Upo th ad nt f llum t *the hyd og* e t at o f th g d ll d s *Th fa o the* t n f th n ime ph ph ryl h h i the p e of ph ph t es t f rm ti n of sol ble t h nt th lubl omp nd gl se-l ph ph te Th esult g n r a e lut c nt ti n of th g d c ll e r a th sm ti p nd he al o th d ff p ess r d fi t O mot m eme t f w t t kes pl f m l gu u p d m l ell n wh h th r l ttl da ly at n in sm t pe r m th d ll Th esult g i r th t g f es f the gu d ll es them t ope R th th d t f d k o f ar l t ely low l ght t ty th ev e t i f p i a p tly i pe t le d ng lt mat l t i l l

Light of low ntensity m gen rally ak ng les eff t tha tro g ll minati n in i duc ng t m t l op n ng Hence tomate often do not op n as w d on cloudy as on cl ar day and often d n t r m i open f r as much f the dayl ght pe r d A defic e cy of wat withi the plant al i du es pa t al t mpl te l u e of the t mate ll ng pe iod of dr ght theref e st mat remai hut cont u u ly or at m t a e p n for only h t peri ds e h day regardles f th light intens t t wh ch the pl nt i expo ed Openi g of th st mat s d not occur in m t p c es at temperatu es app o h g f eezing Hence in cold or even c ol weathe t mates ofte emain lo ed e en wh n the en i onme t l c ndit o ar fa orable t the opem g Noct r al op n ng occu s at time in me p o but the o d t o s wh h nduc th s patte f t matal react n a e not cle ly unde t od

THE PROCESS OF TRANSPIRATION

Th term transp rat n d t d ignat the p o ess wh by water apor lo t fr m pla t Althou h l as lly an evap rat on pr ce tran p ati i c mpl cat d by th r phy c l and phy i l g cal c ndit ons p eva l ng in the pl nt Wher as loss of wat r apo ca oc ur fr m any *part of th plant* wh ch i exp ed t the atmo phere th g t b lk f all tr n p at n o cu f m the l Th e tw k nd of f la t an p rat n (1) t m *tal* tran p rat n which wa te ap lo s o r th ugh the t mate and (2) c t la t nsp ti n wh ch e u di ectly f m the o t d u f e f p d mal walls th ugh th c t l I mo t specie 90% r m e of all f l e t n f the t m tal typ

Dynamics of stomatal transpiration Th dy amics of t m t l t a p t n is c nside ably m e mple than th t f cut l r tr n pirat n In th l a e f m st kind of pl nt the m ophyll c ll do n t fit t g th t ghtly nd the interc ll l r p s between them cup ed by a r A v t bl laby th f a *fill d sp c* th pre ent w th n a leaf b nd d by the wate t r t d w ll f th m ophyll lls W t v p t s r ad ly f m these w t cell walls i t th nte ll l spac If the t m te r cl d the nly eff t f s ch ap at o s t atu t the i t ellul r sp c w th w t p If th t mate pe h weve d ff on f w t p u u lly o c th ough them t the nd tmo phe S h d ff s alw y ccu l s th tm ph ha a p p es q l t g t th n th t w th the *inte ll l* sp ces ti t n whi h eld m p e a l d ng th d yl ght hou of l a day Th two phy i al p es f ap a ti n a d d ff f wate po e b th nt g al t p t mat l t a p t n Phy l g l t l of th mpo e t f t a pi t o s exe ted th ugh th p g a d cl in f th stomat pe u lyd r b d

Effects of environment on transpiration L ht n f th m j fa t c n th t f t a pi at b a e of i c nt ll g effect

the opening and closing of stomates Since stomatal transpiration is largely restricted to the daylight hours daytime rates of transpiration are usually many times greater than night rates which largely or entirely represent cuticular transpiration Since leaves in direct sunlight usually have temperatures from one to several degrees higher than that of the surrounding atmosphere light also has a secondary accelerating effect on transpiration through its influence on leaf temperatures Increase in leaf temperature results in an increase in the diffusion pressure of the water vapor molecules within the leaf

The rate of diffusion of water vapor through open stomates depends upon the steepness of the vapor pressure gradient between the intercellular spaces and the outside atmosphere When the vapor pressure in that part of the intercellular spaces just below the stomatal pores is high relative to that of the atmosphere diffusion of water vapor out of the leaf occurs rapidly when it is low water vapor diffusion occurs much more slowly

Temperature has a marked effect upon rates of transpiration principally because of its differential effect upon the vapor pressure of the intercellular spaces and atmosphere Although leaf temperatures do not exactly parallel atmospheric temperatures increase in atmospheric temperature in general results in a rise in leaf temperature and vice versa On a warm clear day such as would be typified by many summer days in temperate latitudes and with an adequate soil water supply increase in temperature results in an increase in the vapor pressure of the intercellular space Such a rise in vapor pressure occurs because the vapor pressure corresponding to a saturated condition of an atmosphere increases with rise in temperature and the extensive evaporating surfaces of the cell walls bounding the intercellular spaces make it possible for the intercellular spaces to be maintained in an approximately saturated condition most of the time An increase in temperature ordinarily has little or no effect on the vapor pressure of the atmosphere and this is especially true of warm bright days on which transpiration rates are the highest Hence as the temperature rises the vapor pressure of the intercellular spaces increases relative to that of the external atmosphere the vapor pressure gradient through the stomates is steepened and the rate of outward diffusion of water vapor increase

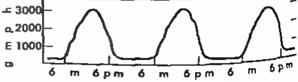
Wind velocity is another factor which influences the rate of transpiration Generally speaking a gentle breeze is relatively much more effective in increasing transpiration rates than are winds of greater velocity In quiet air localized zones of relatively high atmospheric vapor pressure may build up in the vicinity of transpiring leaves Such zones retard transpiration unless there is sufficient movement to prevent the accumulation of water vapor molecules The bending twisting and fluttering of leaf blades and the swaying of stalks and branches in a wind also contribute to increasing the rate of transpiration

Soil water conditions exert a major influence on the rate of transpiration Whenever soil conditions are such that the rate of absorption of water is retarded there is a corresponding diminution in the rate of transpiration

Daily periodicity of transpiration The rate of every major plant process including transpiration is measurably and often markedly influenced by the environmental conditions to which the plant is exposed Many of the environmental factors exhibit more or less regular daily periodicities which vary somewhat of course with the prevailing climatic conditions This is especially true of the factors of light and temperature Many plant processes including transpiration therefore exhibit daily periodicities in rate that are correlated with the daily periodicities of one or more environmental factors

The daily periodicity of transpiration in alfalfa as exhibited on a clear warm day with adequate soil water available is illustrated in Fig 2 A similar daily periodicity of transpiration is exhibited under comparable environmental conditions by many other species During the hours of darkness the transpiration rate is relatively low and in most species water vapor loss during this period may be regarded as entirely cuticular or nearly so The transpiration rate shows a steady rise during the morning hours culminating in a peak rate which is attained in the early hours of the afternoon The increase in transpiration rate during the forepart of the day results from gradual opening of the stomates beginning with the advent of light followed by a steady increase in the steepness of the vapor pressure gradient through the stomates which occurs as a result of increasing atmospheric temperature during the morning and earlier afternoon hours

In most plants if transpiration is occurring rapidly the rate of absorption of water does not keep pace with the rate at which water vapor is lost from the leaves In other words the plant is gradually being depleted of water during the daylight hours In time the resulting decrease in the water content of the leaf cells results in a reduced vapor pressure within the intercellular spaces and a diminution in the rate of transpiration begins Stomates also start to close as a result of the diminished leaf water content and their closure is accelerated during the latter part of the afternoon by the waning light intensity By nightfall complete closure of virtually all stomates has taken place and water vapor loss during the hours of darkness is again restricted



Fg 2 Da ly p r d ty of t a p t of lf lf o th l wa m d y w th ad q at s w t r R t of t p at o p d as g ams p ho p 6 ft q a pl t of (F m M D Th ma a d G H ll P 12 285 1937)

rg ly r enti ly to the elat ely l w rate f u l r t an p at o It s n teworthy that the peak te of tra p at on o cu s dur ng th rly afte n h ur e rr l t ig m re clo ly with the da ly mperatu pe i di ity than w th th d ily per o ty f l ght nt n ty

U der e v r m ntal ndit ns d ffering con le ably f m th po t l t d n th preceding c patt of tr n p r t n period city n y h w on derable a an e fr m the one de cribed On cloudy day for example tomat g ne ally pen l c i pl t ly than on cl ar days d urve for di ly t a p rat o pe d t g e t g tly fl tte ed appe a a comp r d with th ne h wn i F g 2 A cool temp r tu e even a an om what abo tr ezi g greatly d m n she and m y ev e ult e tion of t m t l t a p rat s lting a pro unced mod fic ti th da ly mar h f tra p rati n p r od ty A d f ient l wat r upply i prob ably th mo t mm n f d pa tu e fr m the patt rn of tr nspi at n de cr bed abo e A e d ct i o l wat ont t b l w the fi ld cap c ty (opt m m wat r a a lab l t) re ult n t o ly g r l fl tte in of the t n pirat n perio d ty rve but f qu ntly al ppea ance f th p k f th rv m wh i ea l r the day S n e temp ate zo e g ns d u ht pe r d f gr at r les ity re f c m n e urr dur g th um e m nth and i many hab tat are th l r the th n the x eptn n t an p at n p rod ty rv f th fl ttened d k ed p ak type a e do btedly f f equ t c n

Magnitude of transpiration Tra p r tion f b ad l a ed pe f plant g own n und r t m p t n d t m v r g p t b t 5 g m p m a e de m t f le f a a pe ho Suffi t qu t t f wat a ften l t t a p t n by g tat o r d e f th earth s fa t ha np ts t eff ts ot o ly on l ter l ti but l o n m t r) g c l ndi t Th q nt t e of w te l t p ac e by r ps gr l nd f r t ar th ref a m tter f b t est A a r f c m (ma e) f r x mpl t a p ate q alent t 15 f a n fall du g u al g ng s T aspi t on f de d l g l ak fo e t the th m App l h a m unta n h s b e ti ated s l l ti 17 92 of a f ll p y ar M rked a t u i h al es fr m y r to y r h wev d p di g p n p e ail g cl mat e n d t n

Significance of transpiration T ewpo t re g d ng th gn fi n f tr p t n h e a red b twee th tw xt em f d ng t p oces th t (1) n un d bl ev l r (2) a phy l g l ec ty Neth f th ext eme w ppe t be t able Some of th dental ffect f t n p ati n pp r t b ad antageou t th pl r l t n n of th m s nd p bl f r i tial r even f r t d g t phy l gic l pe t Lik w wh le som f th i ident l t l tra spirati app to be det mental to the pl nt non of tl em is n uch a critical fa t t n that urv al of pla ts on idered n the aggre gate se dang red

Tran pirat on i a ne es ary con equence of the relati n f water t the an tomy of the plant and sp cially t the anatomy f th l a Terre trial green plants are dependent up n atmo pheric car bon di xide f r th i urvi al I terre t ial va c la pl nt th principal c rt n diox de ab l ng f c s ar the moi t me ophyll cell wall whi h b u d il nte c llular spaces in l a Ingre of a b n di x de into th spa occ r m tly by diff on through op n t mate When the to m t are open utward diffu i n of water apor una o d bly occu s and ch tomatal tran p ra tion account for mo t f the wate apo l s fr m plants Altho gh tran p rat o i thus i ffect a idental ph nomenon it often ha marked ndi e t eff t n ther phy olog cal proce se occur r ng n th plant beca se of t eff ts on th inter nal w t r elat ons of the pl nt

TRANSLOCATION OF WATER

In t estrial root d pl ts p actically all f th water wh ch ent a pla t is ab rbed f om the il b ti r ot The wate thus ab rbed i t an l cat d to all p rt f th plant In the tall t t ee (specimens f the coa t redwood *Sequ a s mperi e s) the d ta f m the t f of the de pe t ro ts to the t p f th* topmo t branches i nearly 400 ft a d wat mu t be elevat d f th d tance th ough u h t e Alth ugh few pla t a e as tall a uch ed od th me mechani ms of w ter mo m t a e hel e d to op at i all a ul r spec s The m h nism f the a cent of ap (ll transl ated w ter ontai t lea t t ace f ol t l i plants a d e p c ally t ll t ee was on of th fi t pr ce es to e it the int rest of plant phys l ts

Pathway of water movement The pward mo eme t of wate in pla ts occu s the *xylem* wh ch in t l rg r r t tr nks and br ches of t e a d hrubs i de t cal w th the wood (se XYLEM) In th trunk r l ger b anch of mo t d f t ee *lo ev r* ap mo eme t i e tr cted to f w f the oute mo t an ual layers of w d Th s e pla n why h ll w tree n wh ch the en t al r of ld w od has di teg at d can re ma l e f r m ny ye s Th xyl m f ny plant i a it a d c nt nu s y tem th gho t the pl t Sm ll trands f th s tis ue te d alm t to tl t p f e ry root Oth trand the larg of wh h t tut mp rt nt p rt f tl e e n ram fy to ll p t of e ch leaf In ang o p rms most t a l t on f water oc u thr ugh the xylem l *which* n nl ing l ngat l t bel ke tr ct The e els r f rm d by tl e end to end coal c n f m ny much mall r ell d th f th s lls en u ng t bo t the ame time th t oal e o u l t es the d m ter of ucl e l r ge f m about 20 t *400 μ nd they* m y xten l f m ny f t w th n m re inter upti n than an e as o l l compl t s w ll l gym no perms no es ls ar present a d mo m nt of

water occurs solely through spindle shaped xylem cells called tracheids Vertically contiguous tracheids always overlap along their tapering portions resulting in a densely packed type of woody tissue Individual tracheids may be as much as 5 mm in length Like the vessels they are nonliving while functional in the translocation of water Small more or less rounded thin areas occur in the walls of vessels and tracheids that are contiguous with the walls of other tracheids vessels or cells Structurally three main types of such pits are recognized but all of them appear to facilitate the passage of water from one xylem element to another

Root pressure The exudation of xylem sap from the stump of a cut off herbaceous plant is a commonly observed phenomenon Sap exudation (bleeding) from the cut ends of stems or from incisions into the wood also occurs in certain woody plants such as birch currant and grape especially in the spring A single vigorous grape vine often loses a liter or more of sap per day through the cut ends of stems after spring pruning This exudation of sap from the xylem tissue results from a pressure originating in the roots called root pressure A related phenomenon is that of guttation This term refers to the exudation of drops of water from the tips or margins of leaves and occurs in many species of herbaceous plants as well as in some woody species Like sap exudation from cut stems this phenomenon is observed most frequently in the spring and especially during early morning hours The water exuded in guttation is not pure but contains traces of sugar and other solutes Guttation occurs from special structures called hydathodes which are similar in structure to but larger than stomates In most species water loss by guttation is negligible in comparison with the water lost as vapor in transpiration Like xylem sap exudation guttation results from root pressure

Root pressure is generally considered to be one of the mechanisms of upward transport of water in plants While it is undoubtedly true that root pressure does account for some upward movement of water in certain species of plants at some seasons various considerations indicate that it can be only a secondary mechanism of water transport Among these are (1) there are many species in which the phenomenon of root pressure has not been observed (2) the magnitude of measured root pressures seldom exceed 2 atm which could not activate a rise of water for more than about 60 ft and many trees are much taller than this (3) known rates of xylem sap flow under the influence of root pressure are usually inadequate to compensate for known rates of transpiration (4) root pressures are usually operative in woody plants only during the early spring during the summer months when transpiration rates and hence rates of xylem sap transport are greatest root pressures are negligible or nonexistent

Cohesion of water and ascent of sap Although invariably in motion as a result of their kinetic energy water molecules are also strongly attracted to each other In masses of liquid water the existence of such intermolecular attractions is not obvious but when water is confined in long tubes of small diameter the reality of the mutual attraction among water molecules can be demonstrated If the water at the top of such a tube be subjected to a pull the resulting stress will because of the mutual attraction (cohesion) among water molecules be transmitted all the way down the column of water Furthermore because of the attraction between the water molecules and the wall of the tube (adhesion) subjecting the water column to a stress does not result in pulling it away from the wall

The facts just recited have been made the basis of a widely entertained theory of the mechanism of water transport in plants first clearly enunciated by H H Dixon in 1914 According to this theory upward translocation of water is engendered by the development of diffusion pressure deficits in the cells of apical organs of plants Such diffusion pressure deficits develop most commonly in the mesophyll cells of leaves hence this concept of the mechanism of water translocation is usually associated with the process of transpiration

Evaporation of water from the walls of the mesophyll cells abutting on the intercellular spaces results in an increase in the diffusion pressure deficit of these cells Consequent cell to cell movement of water causes an increase in the diffusion pressure deficit even of those mesophyll cells which are not directly exposed to the intercellular spaces The resulting increase in diffusion pressure deficit of those cells directly in contact with the xylem elements in the veinlets of the leaf induces movement of water from the vessels or tracheids into these adjacent cells Since whenever transpiration is occurring at appreciable rates water does not enter the lower ends of the xylem conduits in the roots as rapidly as it passes out of the vessels or tracheids into adjacent cells at the upper ends of the water conductive system the water in the xylem ducts is stretched into taut threads that is it passes into a state of tension Each column of water behaves like a tiny stretched wire The tension is transmitted along the entire length of the water column to their terminations just back of the root tips Since the tension sustained by the water in the xylem ducts is in effect a diffusion pressure deficit (the osmotic factor in the diffusion pressure deficit of xylem sap is usually small relative to the tension factor) movement of water is induced from adjacent root cells into xylem elements in the absorbing region of roots

The tension engendered in the water columns can be sustained by them because of the cohesion between the water molecules acting in conjunction with the adhesion of the boundary layer of water molecules to the walls of the xylem ducts The existence of water under tension in vessels has been verified in a numbe of species of plants by direct micr c pi exam nat on There is some evidence that under conditions of marked internal water deficiency the ten i s th at

pr liferated int the m phyll ells of e d ells t th b o b g egin f r ot rvat alc l t d ate that a c h ion lue f 30–50 atm would be d quate t p rmit n lo ati n f water t the t p of the t ll st wn tr es H w de o dt f t r al t r d fi e y te o s n d rably x e s of) tm p b bly e g nd d n the wat col m s f m y plant especially w dy spec e

ABSORPTION OF WATER

Th s p w ll b d n ed only from the t dp int f ter est t l r ted plants Con d r o f th b rpti n of wat by plants nece tes a d tand g f the ph al st t f the r t r l a t xt t d r a ou d t n

Soil water conditions E n n th t ght t f l th pa t l fit togeth r perfe tl and t c rts am u t of space e t am g them (e Soil) Th po e p c of a l ang s fr m about 30% f the il v l m t ndy l to bout 50% f the so l l m heavy l y ils In des c ted so l th p p occup ed e t ly by a r t ted o l it up ed nti ely by wat r but m t w ll-d d a l t is usu lly ccupied partly by i d p rtly by w te I s l n wh h wat tal le s l at d t too fa b l w th su fa e n d r bl qua t ti s f wat r may r nt t upp r laye by p ll ty nd bec m a l ble t pl ts l d eg n h e the d ly s n wat r t bl F n m y h m d reg the w t t bl nt n u ly t mitt ntly t o f b low the l rfa e t b n pp ec ble u of wat f m t pl nt l all so l l k g w te tabl t wh h th w te table at a d bl d pth th ly w t a a labl to pl t th t h ch omes n t r l p e ipt t n h h ded by t fi l t igatu n If wa t f ll n appl ed t dry l wh h h m g neo t de bl depth t w ll be- m rap dly d t b ted t depth wh h w ll de- pe d th q a t ty of w t uppl ed pe t nd th pecific p perte f that o l Aft t l d y furthe d p n ng of the m st l y r f so l xte d ng dow w d fr m th rfa rt ally a bec w thi u h a t m t al p ll ty m m nt f w t n a d w wa d d e t n ha bec m xt emely l w n te t Th bo ndary l b t n the m t l of l bo d th d t b l w w ll b d t t n l th dit o f fi ld q l b m th w t nte t f th upp r m t l l ho- m g neo l nt lly f rm th bo t

Th w t t nt f a l th qu libri m d t t lled th fi ld ap ty F ld p t ce g f m abo t 5% t e dy so l t lw t % f th d y ght clay l Th m t t l f l ften m ed n th lab- a r u ll r l l t th fi ld p ty f th s m so l It d fined a th w t r t t f a so l wh h t t ed g t f 1000 t es g ty m ed t t afuge A so l t t fi ld p ty i l t ly m t b t t al o w ll ae at d Soil water co tent at or ne r th fi ld capacity the mo t fa rable for gr wth of m st k nds f plants

A c n derabl prop rtion of the wate in any o l s navail ble n the gr wth f plant The per manent wilti g pe c ntage s the g nerally ac epted ind x f th fra t n of the l wate Th quan tity i me ured by allowi g a plant to de el p w th its ots n o l enclo ed a wate pr of pot unt l th plant p s into a tat of permanent w lt The w te ntent of th o l when th e pl nt j t pa e into th s c ndit on i the perman nt wilt g p r ntage Th r nge of perman nt wilt ng rc nt ges from 3% of the dry weight n r ndy o ls to ab t 20% t l a y lay l ams Ab ut the ame alue is obt i ed fo the p rma nt w lt ng per e tag f a gi en o l re gardl of the k nd f t pl nt u ed

Th d ff n pr u e defi it of the o l water ha tw m) omp ent One is the m tic pr u e of the o l l t n wh h in mo t k d of ils ly f ct n f an atm sphe The the s the att cti f rce b twe n the oil p rt cle d w t r m lecules wh h may attain a ry c n id abl m gnitude e p ially n d y il In m t s l th e t th fi ld cap c ty or higher s l water cont t the f rme of the tw compone ts p p lly r p ble for the il wat diff s n pe su d fic t in drie soil th latt r f th s tw mp e t s Ir o t l ly re p ns ble f r the d ff t pres u e d fic t f th oil wate In th m j r t f il the d ffu n p ess re d f ic t of th o l w t r s l t ze at t rat o l th n l atm at field ac ty and the ty of 15 atm at th perm nent w lting p r entage W th fu the redu t n the water o tent f a l b l w ts p rm e t w lt ng pe nt ge t d ff s p es u e d fic t n ases apidly and at an el rat ng t Alm t o wate a b b- bed by pl t t su h h gh o l w te d ff p e re defi t t s f r th reas n th t th p r ma e t w lt n pe cent t the index of the so l wat which s n l ble t pla t owth (F 3)

Relation of root growth to water absorption Th u e t ely mall branche of th r ot s- tem f a y pl nt term n te ultimat ly n th t t p of wh h th m y be tho d nd often mill s o a s ngle pl nt As e ally mpl y d th te m oot t p r fer t the reg xt d g ba k f m the ap f th ro t f a d tan f t l t eve al cent m t s The t rm al z f a t t t i th root ap Ju t ba k f this a e the g wh ch ell d n a d ll el ngat n ic r a d wh h all g wth n l ngth of ots tak s pl c S e ROOT (BOTANY) J st ba k of th e r g o t th m j ty f spe th zone of oot ha E h o t h r t p o j t on fr m th p d m l ll f wl h t is a t g l pat A ngl o t t p m y be tho s nd f t ha a g ng n l ngth f m f w millimet s up to about e t m t r l t pec th root ha s r h rt) d t ct res b t new n s a

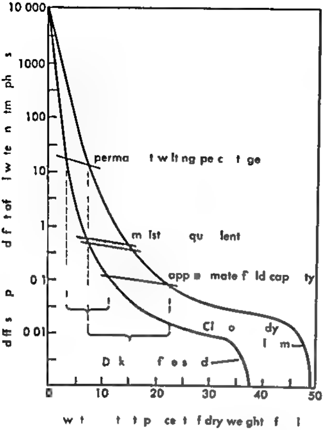


Fig 3 Relation between diffusion pressure deficit of soil water and soil water content of two soils over the range of soil water contents Horizontal brackets show the range for each soil over which water is readily available to plants The vertical scale is logarithmic (From M B Russell Am Soil Sci Soc Proc 4 51–54 1939)

stantly developing just back of the growing region of the root as it elongates Most absorption of water occurs in the root tip regions and especially in the root hair zone Older portions of most roots become covered with cutinized or suberized layers through which only very limited quantities of water can pass

Whenever the diffusion pressure deficit of the water in the root hairs and other peripheral cells of a root tip exceeds that of the soil water movement of water takes place into the root cells If the soil water content exceeds the field capacity water may move by capillarity toward the region of absorption from portions of the soil not immediately contiguous with the root tips and the supply of readily absorbable water is maintained in this way Elongation of the root although slower in most species in relatively wet soils also helps maintain contact between the root tips and untapped portions of the soil water Many plants much of the time grow in soils with a water content in the range between the field capacity and the permanent wilting percentage In this range of soil water contents capillary movement of water through the soil is extremely slow or nonexistent and an adequate supply of water cannot be maintained to rapidly absorbing root tips by this means In such soils maintenance of contact between the root tips and available soil water is assured only by continued elongation of the roots through the soil Mature root systems of many plants terminate in millions of root tips each of which may be visualized as slowly advancing through the soil absorbing water from around or between the soil particles with which it comes in contact The aggregate increase in the length of the root system of a rye plant averages 3 1 mi/day Calculations indicate that the daily root elongation of this plant is adequate to permit absorption of a sufficient quantity of water from soils at the field capacity to compensate for daily transpirational water loss

Mechanisms of absorption of water As previously indicated the tension generated in the water columns of a plant most commonly as an indirect result of transpiration is transmitted to the ultimate terminations of the xylem ducts in the root tips As soon as the tension in the water columns exceeds the diffusion pressure deficit of contiguous cells in the root tip water moves from those cells into the xylem This activates further cell-to-cell movement of water in a lateral direction across the root and presumably in the establishment of a gradient of diffusion pressure deficits increasing progressively in magnitude from the epidermal cells including the root hairs to the root xylem Whenever the diffusion pressure deficit of the peripheral cells of the root exceeds that of the soil water movement of water from the soil into the root cells occurs There is some evidence that under conditions of marked internal water stress the tension generated in the xylem ducts will be propagated across the root to the peripheral cells If this occurs greater diffusion pressure deficits could develop in peripheral root cells than would otherwise be possible This absorption mechanism would operate in fundamentally the same way whether or not the water in the root cells passes into a state of tension The process just described often called passive absorption accounts for most of the absorption of water by terrestrial plants

The phenomenon of root pressure previously described as the basis for xylem sap exudation from cuts or wounds and guttation represents another mechanism of the absorption of water This mechanism is localized in the roots and is often called active absorption Water absorption of this type only occurs when the rate of transpiration is low and the soil is relatively moist Although xylem sap is relatively dilute its osmotic pressure is usually greater than the diffusion pressure deficit of the soil water when the soil is relatively moist A gradient of diffusion pressure deficits can thus be established across the cortex and other tissues of the root along which the water moves laterally from the soil to the xylem There is evidence however that a respiratory mechanism as well as an osmotic mechanism may be involved in the correlated phenomena of active absorption root pressure and guttation

Effects of environment on absorption Any factor which influences the rate of transpiration also

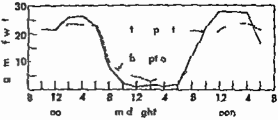
i fl n es th r te of ab orpt n f w te by plant d i e v r Cl m t d t ons may the f re d rectly affe t ates f w ter ab orpti n a d ol c ndt n d r tly ffe t t an pr t on Low o l tempe atu es e in a an e n de ably abo f e zi g r t d the r t of ab orpt of wat r f y m ny pec es Th ate of water b pt n by un ll w r pla t f ample d ap dly a th so l temp tu e d bel w 55 F

W thin l mit the gr ate the upply of a ailabl o l water the gr ter th p s ibl rat of water ab pt H h o l wate tent e pe i ll th se app a hi g at t n e ult i de r a d w t r ab pt n r te i m y spec e becau of the a np nying defi ie t l aer t I the at m ph f h l th yg c n ntr t o s l r nd th l n diox de con ent ati n s h gh r tl n th tm phe e pr pe In gen ral the defi y f o yg n in uch o l pp a s to b a mor gn fi a t f ct au n r tarded ate f ab pt n th th e c f c bo di x de Th r t d n effe t o the r t of w te b- so pt n r l ted w th a et d g effect n th te f t pirat n (s e PLANT RES IRA TION)

L k w e if th l ol t n attai ny d er ble o c tr t on of l t wat r absorpt by th r ta ded In mo t o l th e een t t n f th l l t n is o low th t t a a gl g bl fa to n affect ng r te f wat b p- t n In l lkal oil h we er the n e t at f th l lut n m b om eq le t t m ny tm phe nd o l a few p of pla t able t rv wh o ted n u h s ils

Wilting D ily t h in the wate o t nt f pla t m r m ked in m rg tha n th e f f nt Th f m l a phe m f lt ng exh bited by th lea es d me ime th g f pl t p t l ly h rba eo p c d ct ual d n f th fa t In h t br ght w ath th l a of m ny pe es f pl t ft w lt d r ng th fte n nly t g n the t g dty du g th ght h ur e en f dd t n l w t d d l y r nf ll i ig ti Th tyt f w lt a ti ferred t t mp ary t a ie t w lti g l le l r ult f om a te f t a sp r t e s f th at f t b pt l r g th d yl ght h u A a ult th t t l l me f wat th pl t h nk lth gh t q ll all g n o t s- I g n al d m ut o w te t t k test th l af ll d wilt g s ndu d h e th tu go p f th l af ell s re d ed uffi e tl

d wh n bj w lt g s ot d e m bl p t w lt ng ff q t oe r n In p nt w lti g rr p d t nly p rt l l f t g h th l f ll nd d es t ult i bl d oop ng f ldi g r ll g f th l Le es e t r t to th d t n f t n t wilt g alw pa fi t th gh th t g f ap t w lt g O i r f th n ble first tag f w t g fm t u l br gh t warm d y



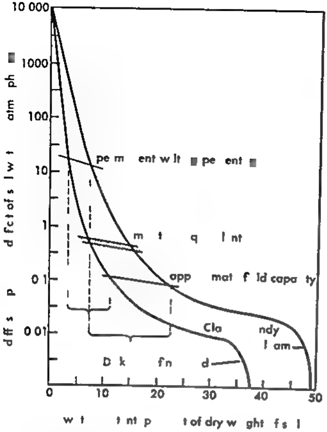
Fg 4 C mp t d ly p d t of t p o u d ob pt n of wat l bl lly p n (P s to d L) (F m P J K m Pl t d S l W te R l t h p M G w H ll 1937)

on wh h n i onm ntal ond t ons re not e er e ough t d i e the more ad a d stag f tran s t w lt g

Co firmat n of the inferred caus of t an ent w lting h bee fu t h d by inve t g t ons of the mp at e daily je i d c ties f tran p rat on and the ab o ption f w ter (Fig 4) As illu trated in th figu th r i a d stin t lag n the rate of ab- s rpt n f water as c mpared w th the of t a sp r tion dur ng the daylight ho rs Du ing the night ho rs n th cont ry the rate f wat ab- s rpti n is e nt n ou l gre t r th n the rate f tr n pirat on Th s d ing the daylight h the t ues f th pl nt a e b ng p ogr s vely depleted of w te whe a the st re of wat r w thin th pl nt is b ng teadily pl n l d d i g the n ght h u The l g n the rate f b pt n behind the te of tr n pi ti n during the daylight hours ap p a t es lt la gely fr m the el tiv ly high st n f th li g o t ell t the p s ge f wat r ac them

Both pient a d tr ent w lt ng should b di t gu hed f m the m drastic tage f perm nt wilti g The t ig f w lt g att in d nly wh th t is an tu l d fic en y f wate the il and pl nt will n t rec e from p rm ent w lt g nles th wate content f the oil wh h t s ooted c a e l il whi h g adually dry g ut tr e t wilt ng lowly gr d o er i to perma ent w lt ng E ch s es n ght re ve y f the pl t f om t mp ary w lt g t ke l ng nd i less omplete u til fi ally en the sl ght t er y f l t tak pl c d r g th n ght

Alth ugh th st mat s ar gen ally l ed d ng p rm nent w lt t c l t an p t n n t e Pl nt n a tat of perma t w lt g t e to b rb wat b t r l w te R t t n f t g dty is n t p l le h w e b cau e the te f tr n p r t on e en from w lt d pla t e eed the at of ab orpti n f w t f m a wat ntent D g perm n nt w lt g th fore low b t r dy d m nut o i the tot l v l m f w te w th n th pl nt a d g d l ten ifi at on f th th hydr dy m ys- t m T n i tl w t r lumn of pe m ently w lted pl nt ar re) ti ly h gh a d h bee mti mat d t it in lu of 10 atm n s m t e s l th ugh th s p bably n xt m fig re



Fg 3 Relat b twe d ff s o p essu def cit of o l water and s l wat co t nt of two so ls o er en t ge of o l wate onte ts H nt l b ck ts sh w the range f ea h so l ve wh ch wat r is ad ly ava lable to plants The t cal ale log thm (F om M B R ssell Am S l S Soc 4 51–54 1939)

stantly developing ju t back of the growing region of the root as it elongates Most ab orption of water occurs in the root tip regions and especially in the root hair zone Older portions of most roots become co ered with cutinized or suberized layers throu h which only very limited quantities of water can pass

Whene er the diffusion pressure deficit of the water in the root hairs and other peripheral cells of a root tip exceeds that of the soil water movement of water takes place into the root cell If the oil water content exceeds the field capacity water may mo e by capillarity toward the reg on of ab orption from portions of the soil not immediately contiguous with the root t ps and the supply of readily absorbable water is maintained in this way Elongation of the roots although slower in most pecies in relati ely wet soils al o helps maintain contact between the root tips and untapped p rt on of the oil water Many plants much of the time grow in oils with a water content in the range between the field capacity and the permanent wilting percentage In this range of soil water contents capillary movement of water through the soil is extremely slow or nonexistent and an adequate supply of water cannot be mainta ned to rapidly absorbing root tips by this means In such oil maintenance of contact between the root tips and available soil water is assured only by continued elongation of the roots through the soil Mature root systems of many plants terminate in milli s of root tips each of which may be visualized slowly advancing through the oil absorbing water from around or between the oil particle with which it comes in contact The aggregate incre se in the length of the root system of a rye plant a er ages 3 1 mi/day Calculations indicate that the daily root elongation of this plant is adequate to permit ab orption of a sufficient quantity of water from oils at the field capacity to compensate f r daily transpirational water lo s

Mechanisms of absorption of water A previously indicated the ten ion generated in the wa er columns of a plant most commonly as an indirect re ult of transpiration is tran mitted to the ultimate terminations of the xylem duct in the root tip As soon as the tension in the water colum exceeds the diffu ion pressure deficit of contiguous cells in the root tip water moves from those cell into the xylem This activates further cell t cell movement of water in a lateral direction across the root and presumably in the e tabli hment of a gradient of diffusion pressure deficits increa ing progressi ely in magnitude from the epidermal cells including the root hairs to the root xylem Whenever the diffusion pressure deficit of the peripheral cells of the root exceeds that of the soil water movement of water from the soil into the root cells occurs There is some evidence that under conditions of marked internal water tre s the ten i n generated in the xylem ducts will be propa ated across the root to the peripheral cell If this occur greater diffusion pre sure deficit could develop in peripheral root cells than would otherwise be possible This ab orption mechani m would op e ate in fundamentally the same way whether or not the wate in the root cells pas into a state of tension The process just described often called pas ive ab orption accounts for mo t of the absorption of water by terrestrial plants

The phenomenon of root pressure previou ly descr bed as tl e basis for xylem sap exudation from cuts or w unds and guttation repre ent another mechanism of the ab orption of water This mech an m is localized in the roots and is often called active ab orption Water absorption of this type only oc urs when the rate of transpiration is lo and the s il is relati ely moist Although xylem p relati ely dilute its osmotic pre ure i u u ally greater than the diffus on pressure deficit of the s il wate when the soil is relatively moi t A g adient of d ffusion pressure deficits can thus be e tablished cross the cortex and other ti sue of the root alo g whi h the water moves laterall f om the oil to the xylem There is e idence ho e that a esp ration mechani m as well as an o motic mechani m may be in lved in the correlated phe mena of a ti e ab orption root pre ure and gutt tion

Effects of environment on absorption Any fac t r which influence the rate al o

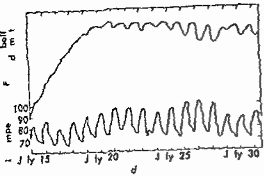


Fig 6 D ly t d met of o c tt b ll g th fi t 5 day the b ll w s t ll g w g (F m D B A d d T K Pl t Phys l 18 261 269 1943)

The g ow ng c ll th te n l node of th to- mat tem b usly nt nu t btain w t r d g th d yl ght h u wh le the r t of th tem s l g w t r d me of the water t l z d t the r th pr b bly c me from th lls of low r od I g l a th la t t e ampl llus- tr t a t ly me temati egio s uch s grow ng t m d t tip a d enla gi g fruits nd r c nd t n f intern l t d fi y app ently de el p h gh d ffu t pre d fic t than other t u (e MERISTE t APICAL) H e wat r ft n t uest m e t w d u h r g n when n t t m l wat d fi en y of n d bl mag tu le h s de l p d w thi the pl t H wever un d r d ti ns f d t c te l w t r d fi t p- p a hing r orre pond ng t a tat of p rma nt wilt ng w wth of all m t tems s greatly ta d d t h h ted

Drought resistance Th term d ought ref rs n g n al t p r d du ng wh h the l c ntai l ttle no w t r wh h a ilable t plant I r latn ly humid l mate h pe d a f e- qu t a d ld m l l g d rat pt t r t n local hal t t Th m re a d a l m t t ge l the m re f qu t the occu n e of droughts nd th l ge the r du t on M t p s of plant n s rv h rt dry p riod w thout r ous ju y b t l ng d p d f l wat d fi y t h ghly inj or l th l t all ex pt th e p c es of pl t w th well d l ped c pa ty f r dr ght es t

M t pec h h g w em d t g n u h th e l th so thw t rn U ited State and d t M r n l lls dry h b tats m t be d ght r nt f the w d n th Ann al pec wh h g w n m y r d g n du g h rt a y p ll a pt n t th t t m t S h p mpl te the br ef l f y l f m eed s ed du g a p r od wh n m l w t a il bl a d e urvi e ar d gion bec u th y ev de th tha d d ght

S ul t h a t a l d t m t m de t R a d l ft and g t lo- cally dry hab tats u h sand dune and beache in hum d cli nat eg on Succulent are able to urvive long dry pe i d beca e of the relati ely l rg qu nt ti of water which accumul te in me pe s n fl hy st ms and in oth r pe ie in fl shy lea e du ing the ceasi n l per od when o l water a ilable M ny su culents can live for mo th m u h stored water

Th e pla ts wh ch are dr ght re tant t the t ue t s n a e th se whose cells can tol rate a ma ked edu ti n in w t r c nt nt f r e te ded pe r d of time w thout i jury Ma y hr l bv spec s of sem de rt reg ons ha e this pr perty Certain st ictu al features u doubtedly aid in the urv al of uch pla t for long per od in arid hab tats Many xe opl ytes (plant that an e du e p r ods f d u ht) h e exten o t system in propor ti n to their tops uch a t uct al ch racte i tic aids i mainta ni g a upply f water t the aerial p t n of the plant l n er than would otherwi e be po ible (see ECOLOGY) Oth r drought re i ta t spe ie are cha a t ri ed by h ing d min ti e le the t ansp ng f ce f the plant may thu b mall relat t th al pt a a it f the r ts I t ll the peci s the lea es ab i (fall) w th th ad t of th dry a on th s greatly red c g tran pi t n p r pl nt dur ng the pe d of gr at t intern l t s in th hydrody n mic y tem

D sp t y tru tur l fe tures which m y l elp ma nta th nt rn l w te pply hri bl y plant f em d regi n r gula ly nde go a gradu l de pl t on n the t re f wate w th n th m and a gr d al nt n fi at n f the t pre iling in th nternal hydr dynami syst m o r dry p riods ft n l ting f mo th Only dr ught s tant pe a d re th o d ti n which is n s en e a t te of perm ent w lt g f r l ng peri d f time with ut inju y A fund me tal f cto th d ught t nc of pl nt th refore ap- pea s to b a apac ty f the ells to end re ub ta t al red t on n the r w ter content with t ffe i g nj ry Thi ap ity pr bably is ba ed in p rt t uct ral features f th cells of u h p ci and n p t n the d t ncti e phy io- l g al p op rt es of the pr topla m S e PLANT A I RAL NUTRITIO OF [B S M]

Bibl g phy A S Craft H B Cur nd C R St k g *Wat i th Phys l gy f Plant* 1949 H H D o *T an p ati n a d th As ent f S p i Pla t* 1914 P J Krame *Plant and Soil W t r R t on h p* 1949 N A M x mo *Th Pl nt R l to Wat* 1929 B S Mey r and D B And r n *Plant Physiol gy* 2d ed 1952 B T Sh w (ed) *Soil Phy cal C nd t ons d Pl t G o th* 1952.

Plant anatomy

Th area of plant sc en erned with th n t r al tr ctu e f pl ts It de l both with mat r tru tu e a d w th th i or g n d devel pm nt

As previously mentioned the permanent wilting percentage an important index of soil water conditions is defined as the soil water content when a plant just enters the condition of permanent wilting. Sunflower is the most commonly used test plant in making determinations of the permanent wilting percentage of a soil. Permanent wilting of the basal pair of leaves judged to have occurred when they fail to recover if placed in a saturated atmosphere overnight is taken as the critical point in the measurement. The range of soil water contents between the first permanent wilting of the basal leaves of sunflower plants and the permanent wilting of all the leaves is called the wilting range. The water content of the soil at the time all the sunflower leaves have become wilted is termed the ultimate wilting point. In general the wilting range is narrower in coarse textured soils than in fine textured soils and may be 10–30% of the soil water content between the field capacity and the ultimate wilting point. Although plants cannot grow while the soil in which they are rooted is in the wilting range many kinds of plants can survive for considerable periods under such conditions. This is especially true of many shrubby species indigenous to semi desert areas.

Internal redistributions of water For convenience the processes of transpiration, translocation of water and absorption of water are often discussed separately although there is a close interrelationship among these three processes. The hydrodynamic system of a plant is essentially a unit in its operation and changes in the status of the water in one part of a plant are bound to have effects on its status in other parts of the plant.

Whenever a plant is saturated or nearly so with water differences in diffusion pressure deficits from one organ or tissue to another are minimal in value. But whenever the rate of absorption of water lags behind the rate of transpiration an internal water deficit develops in the hydrodynamic system of the plant which in turn favors the establishment of marked differences in diffusion pressure deficit from one part of the plant to another. Under such conditions redistribution of some of the water present from some tissues or organs of a plant to others generally occurs.

Internal movements of water from fruit to leaves and vice versa seem to be of common occurrence. Mature lemon fruits while still attached to the tree exhibit a daily cycle of expansion and contraction (Fig 5). The lemon fruits begin to contract in volume early in the morning and continue to do so until late afternoon. Since transpirational loss from a lemon fruit is negligible it is obvious that during this part of the day corresponding to the period of high transpiration rates from the leaves, water is moving out of the fruits into other parts of the tree. Most of this movement probably occurs into the leaves. During the daylight hours the diffusion pressure deficits of the leaf cells presumably increase until they soon exceed those of the fruit cells thus initiating movement of water from fruit to leaves. During the late afternoon and night hours the volume of the fruits gradually increases, indicating that water is now moving back into the fruits. During this period transpirational water loss from the leaves is small, leaf water contents increase and the diffusion pressure deficit of the leaf cells diminishes. Less of the absorbed water is translocated to the leaves than during the daylight hours and more can move into the fruits despite the relatively low diffusion pressure deficit of the cells of the fruit. Marked daily variations take place in the diameters of lemon fruits even under environmental conditions which result in no observable wilting of the leaves.

In growing cotton bolls however as long as enlargement is continuing, increase in diameter continues steadily both day and night and even during periods when the leaves are severely wilted. Movement of water is obviously occurring into the growing bolls without interruption during this period. Once the bolls cease enlarging however reversible daily changes occur in their diameter similar in pattern to those which take place in mature lemon fruits (Fig 6). Similarly it has been shown that in a tomato plant the topmost node within which growth in length occurs continues to elongate at approximately the same rate both day and night. The stem below the first node however shrinks measurably in length during the daytime and elongates equally at night undoubtedly as a result of reversible changes in the turgidity of the stem cells.

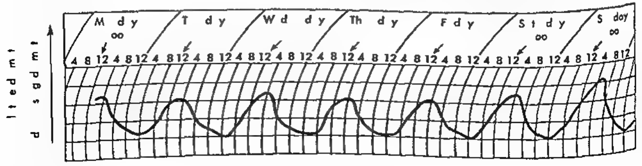


Fig 5 Daily variation in the diameter of lemon fruits (From E T Bartholomew Am J Bot 13 102–117 1926)

l g c l hab tat data made for a ı us sta ds of g t t on ı oth r w ys than int types f plant c mmun t e They a be arranged to de cr be grad ent e ı s contin or function in cor e sp nden e w th ario h bitat fa to Pr p t e f the veg t t n the th n speci s c mp sit on ca b u ed t help cha acte e plant commun n T tal yield p unit ar a uch as t ns f f age/he tare or cub met r of w od/hect re l f fo m d persal o poll at n spe t a and t t l e tent of c tain chemi al eleme t all can be u ed as pr pert of pl nt ommunitie

Plant and an mal which ar as iated al o form mmun ty a bi o no Usu lly the plant mmunity form the fi d sub t at m for th ani mals wh ch may b mobil e BIOLOGICAL PRODUCTIVITY

Structure of plant communities Plant commu t h a tru t e va ying n complexity f m m ny l v ed f re t to uni t atal p lar or h t des rt crypt gam ommun ty M low d tall h rb l w d tall h ub and several t ee lav r m y be p e t a d th r m y b p pl yn s e t e n the t e t ks and bt n h s I compl x mmun t e th a p t h nges th ugh ut th ye r s a io s gro p of pl t thro gh the tag f th r l f cy l s at d ffe nt time G n the spec l t f r a t d f eg tat n it s pos ble t a sume mu h about the str tu of the pl t mmun ty f om knowl dge of the p c ned If we a o f r tudyin pl nt mm iti add t on t nd dual pl ts that n a io c mm it s nd d al pe ı s beh d ff e tl Thu fi w d *Ep l bi m a gu t f l am* oc r many f r t ommun t e *of th* N rthern Hem ph It ually t r le but it fl l pr l f at ab nda tly wh n th f r t d t y d hy fi e tti g p odu ı n w h b t t nd opp rtun ty f n w plant comm ty S SUCCESSION ECOLOGICAL

Dynamics Th fun t on ng f pla t e mmu ti s l g t the phys l g l pro e t k g pl the d d l plants of wh ch th *om m* t t mp ed b t gn fi t nte cti s betwee pl t m d fy f r mple th w te r g m f f t floo pla t d the a b d d m d a l bl f ph to y the is by th g en pl t The ph t l g al t l r f ndı du l pl t t f t f the hab t t th modi fied t l g l t le n e by mp t t n w th th pla t th mm ty

Th l t s f pl t mmu it m en n m l a y t m ı ed nd ari t f t r of the m t Th pl t rea t t h fe tur l th nm t g l l mat l g e t m t al t p g pl l f at r th o di t lor l l mates g und te w d w d p o t l a d the b t a l ble to th b t m n d M m t mpo t t pa t f th l ta l th s l ed a d l c l zed tate Pl nt mm t n d ff r t g gr ph al r g d ff pe h ps fi t f ll bec the fl r l l l th d ff r nt r g d ff

th ugh ec l g cally th r gion may be quite mı lar The c mb n d and interacting ffects of all th e g oup of f ctor pr duce at a gi en time particular e o ystem or mb nation f plant com munity n t envir nm t in wh ch tl e veg tation and en ironm nt l p ope t e stand in f inctional rel t on hip t a h other Thu t n a c nt n ntal scal the change in regionally r pre ntat v plant ommunities from the short gr ss high pla ns of Col rad e t thr ugh the tall gr s of Kan as to the d cidu us forest of Ohi can b inte preted as a rea t on to decreas ng mo tu alon a given an nual isotherm uch as 11 C In the m untain r nges of the w stern Un ted St tes tran iti ns from sh d cale (*At iplex conf tif l a*) de ert t sag bru h (*A tem s a t dentata*) sem de ert to oakb ush (*Q e s gamb lli*) chapar al to spru fir (*Pi a ngelmani Abi s las oca pa*) con ferous fo e t t alp ne herb ceous veg tat on are related t altitudinal cha ges in the continent l climate I ec p tatio incre e f om 100 to 1000 mm wh r a t mperature d op f om 10 t 0 C as an nual m ans S e ECOSYSTEM

Other factors These reg onal hang s in egeta t on an be f un l when nly l m te change the other fa to s of the e v ro ment a e fi e l at ome pa t ular alu If they ar fi ed at another set f val ı s the equen will be ju t d ffe ent A m d ifi atio f th el f fact in the M ddle W te n ca e a hift f m the well drain d uplands t r ve fl dpla ns w ll lt r vers e f re t c mmu n ti f r ou typ all alo g th ı the m If t mpe ature d a ı c lly lowe ed as ı the Arc t eve 100 mm f p e p tat on w ll re ult n *bo getat* n Th eq ı e of pl t mm niti wh ch o pond to a chang n on f ct r of the e sy t m s a f n ti n f those oth r factors f the sy t m l ch ha h en on t t

Climax Stat tu t n re d crib d ab ve How e veg t t on ı dynami t l s Ci n a fix d t f the v o mental fa to pe ating on a b e this e w ll change ı the typ of pl nt c mm t it supp ts t con tantly de re ng r te unt l a te dy tate s atta ned Th e qu l b um t ge a cl m x plant communit y At s ch n eq ılibr m wh h m to be r ch d n f w h dr d y a d p nd ng on the e osy t m th effects ol cl m te in determi ng th kind of eg t t often becom p ram unt Although the eff t f l m te ma b m p amo t n m y c y t m ı th r w th t em s of o e of the othe fa to the effect of th s l tt r f t r m y per t ı d fi it ly *Th* y oa e g ined ndy il p r t m t tl may c nt u t upp rt a pl nt comm nity q te d ffe nt from th t n the u r und *ng hard* land as the Sa d Hill f Ne bra ka with th ı tall gra s g t t on s ounded by cl max m d a d ho t g a

l add ti t th h rt t rm ge s s m nt on d abo e the e e ch nge f ıl en ı nme tal f c t r th m l es wh h r lt n h to ic l ch nge s pla t omm n t I a ı f pl t ew to th flo a the ch stnut bl ght ı t the h dw od f

The plant anatomist dissects the plant and studies it from different planes and at various levels of magnification. At highest magnification he examines the smallest units of plant structure, the cell; at intermediate magnification he observes the organized aggregations of these cells, the tissues; and at low magnification he determines the arrangement and interrelations of tissues in plant organs such as root, stem, leaf, and flower. At the level of the cell, anatomy overlaps plant cytology, which deals exclusively with the cell and its contents. Sometimes the name plant histology is applied to the area of plant anatomy directed toward the study of cellular details of tissue. *See* PLANT ORGANS; PLANT TISSUE SYSTEMS. [K.E.]

Bibliography: E. Boureau, *Anatomie Végétale*, 3 vols., 1954–1957; H. A. De Bary (tr. F. O. Bower and D. H. Scott), *Comparative Anatomy of the Vegetative Organs of the Phanerogams and Ferns*, 1884; A. J. Eames and L. H. MacDaniel, *An Introduction to Plant Anatomy*, 2d ed., 1947; K. Esau, *Plant Anatomy*, 1953; A. S. Foster, *Practical Plant Anatomy*, 2d ed., 1949; A. S. Foster and E. M. Gifford, Jr., *Comparative Morphology of Vascular Plants*, 1959; G. F. J. Haberlandt, *Physiological Plant Anatomy*, 1914; B. D. Jackson, *A Glossary of Botanic Terms*, 4th ed., 1953; H. Lundegardh, Zelle und Cytoplasma, in K. Linsbauer, *Handbuch der Pflanzenanatomie*, vol. 1, Lief. 1 and 2, 1922; C. R. Metcalfe and L. Chalk, *Anatomy of the Dicotyledons*, 2 vols., 1950.

Plant classification

The phase of plant taxonomy concerned with the systematic arrangement of plants according to their relationships. Plants may be classified in many ways—by similarity of parts, complexity of structure, means of reproduction, or by combinations of these and other characteristics. However, the botanists of almost every country except Great Britain use the Engler-Prantl system of plant classification or modifications of this fundamental system. This system, set forth in *Die natürlichen Pflanzenfamilien* by the German botanists A. Engler and K. Prantl, is dominant in a majority of the large herbaria and published floras. Based primarily on natural relations, the Engler-Prantl system employs the following categories.

The basic unit of taxonomic work is the species, which is a grouping of individuals having essentially the same structure and life history. When a number of different species are found to have certain fundamental characteristics in common, they are grouped into a larger category called a genus. In the same manner, on the basis of inherent similar characteristics, related genera are grouped into families, families into orders, and orders into classes. The classes of the plant kingdom are frequently arranged into twelve different phyla. Each phylum represents one of the largest divisions of the plant kingdom. Its members have fewer characteristics in common than are found in the families or any of the lesser categories. For example, a vascular system (specialized food- and water-conducting tissue) is the one main characteristic of all the members of the phylum Tracheophyta. All the major classification groups may be broken down into smaller categories designated by such terms as subkingdom, subphylum, suborder, subfamily, tribe, and subgenus. Species may also be subdivided into such smaller categories as subspecies (ssp.), variety (var.), subvariety (subvar.), form (f.), and clone (cl.). The name of an order usually ends in *-ales* (Rosales), a suborder in *-ineae* (Rosineae), a family usually in *-aceae* (Rosaceae), a subfamily in *-oideae* (Caesalpinioideae), and a tribe in *-eae* (Pomeae). The term taxon is used to designate any category whatever its rank: species, genus, family, or order. However, no one of these categories can be defined precisely. Each botanist fixes the limits according to his own view. *See* PLANT KINGDOM. [P.D.S.]

Bibliography: *See* PLANT TAXONOMY.

Plant community

A plant community is an association of plants. Plants of various species are found growing together as vegetation, and certain combinations of species are found repeated in homogeneous areas of similar ecology, or biotopes, so often that generalizations can be made concerning these combinations. A plant community, then, has a certain species composition. A list of the plants occurring in a stand can be made by species names and by life forms. A list of all species is desirable; usually only vascular plants, bryophytes, and lichens can be recognized in the field. It is often necessary to take herbarium specimens, and such vouchers still document the study permanently. Ordinary taxonomic nomenclature is usually used, but a constant effort to improve this and to split the species into biotypes of more uniform relationships to environments must be made. The species list is limited because within a given community the rate of increase of species number with increase in area is inversely proportional to the area investigated.

Characteristic species. Some kinds of plants are characteristic of a particular species combination; they are found only in one kind of combination wherever they occur, or regionally, or perhaps locally. Other plants are always found in a particular plant community. Still other plants occur in several kinds of communities; some are almost ubiquitous. Advantage is taken of such facts to classify the plants found into characteristic species which are exclusive to a given kind of vegetation or always found in it; differential species which occur in only one of two related communities; and accompanying species which show little or no preference. The value of a given plant community as an indicator of habitat is determined largely by its characteristic and differential species, and it is by these species that plant communities are recognized. *See* PLANT SOCIETIES.

Properties of plant communities. It is possible to arrange the list of spe... a... iated

m ru t onl ne of m th 3000 ki d of nt ru t ha b e m l rl de tr ctt e n th at g i g s f th w rld ard t nunu y me a e wh t at barley ry and ma y a e Th *H lm tho p rum* d a of ric wa nc p l a f a fami n wh ch a m lli n mo e peopl di d n I d i 1943

Pla t d ea ed e p tenti l U S cr p p od by ab ut 7 ye r qui le t t pr d t on ab t 2 000 000 a re Th s l sd not lt de t f ontrol me ure su h a sp ay a d afte rvest l es Sp y g potato t ntr l late ght olt n t $3 an a r spr y ng fr t m l ly tly a d di a d p st c t l on t tes ab ut 50% f th field ts n p odu ng a a

Pl t d a da th t t ma atu e b t c Mu h f the w ld i w un e fed nd a ut f od sh rt ges ften ccu n n nv The t ti t d t bec me wo e p p lati n r a bv m ny m ll n each ar Pl t d a es old a d ew r c t l m t g f t n f d p d to Th d g e to h h th y b nt lled will h lp dete m ne h the the w ld e n feed ts rap dl gr w g pop lat n [E.C.S]

Nature of diseases I the br d n d e n pla t m y l id ed nv ph olo i l abn rm l ty wh h r od es p th l g l ymp- t m educ the m a th t al f pla t p d t r k ll th pl to ny f t pa t Dam g d i w d l ght i p dat n f n e t th r a m l n t ally alled d lth ugh h nj y t li g pla t may s lt n a phy l g l d t ba e wh b t t ly d Dec y f t r g g l k t be s a d ont d a e b l pl t part e l deca f l mb d a o ly by te s o f th d fi t alth h th p oc m v b m l

D pl t i ally d n d b b o m l tes n pp a ll d ympt m by th p es f p th g n th pl nt Som d h eve h ob mpt m po- t t X f r mpl d th y ld of po- t toes w tho t app t ha th pp ce f th pla t

Th ympt m f pl nt d e es ma b d th er f ll ny p s f th pl t l f tu g (w lt) g wth (l yp tr ph nd by pe pl t t t g (h popl a) a o th ha ges th t t nd mp t f th pl t m affect a v p t f th pla t t r tag f g wth A p d d th f f l g lt lled bl ght (F g 1) h a loc l ed ecr es lt f l pot d f t pots. Ne- f t m f k esult k s (F g) W lt g m be l w p d a d t n lly m t p n ed d y th m t so l Nec o- r l ll f ll w pers t t w lt g O r gr wth mpr sed p m ly f d ffe e tated ll lled g ll (F g 3) th t m t m be- les c mm nly ed t des g t thes t

F g 1 C mmo b t l bl ght of b (F m J C W lk *Pl t P th l gy 2d d M G w H ll 1957*)

F g 2 S th m b ct t wlt f t m t Th pl t h w t f ep o ty d wlt (Aft K lm f om J C W lk *Pl t P th l gy 2d d M G w H ll 1957*)

F g 3 C own g ll t ppl (A J R k f m J C W lk *Pl t P th l gy 2d d M G w H ll 1957*)

est of eastern North America which almost totally killed one of the former leading dominants in this forest or the postglacial climatic changes which have been so well documented by pollen analyses of bog sections are examples If one of the factors determining a plant community changes it is an axiom of plant ecology that the community will change See CLIMAX COMMUNITY

Distribution The distribution of plant communities over the face of the earth has been studied more from a physiognomic than from a floristic viewpoint Repetitions of physiognomically similar types of vegetation do occur in widely separated parts of the earth with similar climates The evergreen sclerophyll chaparral of winter wet summer dry mild climates in the Mediterranean region of Europe Australia South Africa California and Chile is an example of floristically completely diverse regions having at least superficial similarities in the appearance of plant communities because of their similar structure See CLIMAX PLANT FORMATIONS

Classification Finally plant communities may be classified The most widespread system is that developed by J Braun Blanquet and used extensively in Europe Floristically similar stands of vegetation with some characteristic species in common are abstracted into associations denoted by the terminus etum Associations are combined into alliances (ion) these into orders (etalia) and these into classes (etea) Classes in general coincide with broad physiognomically defined kinds of vegetation or formations The next higher unit is a floristic one recognizing such differences as those between the Mediterranean flora and that of central and northern Europe Obviously if two regions have different floras they must also have different plant communities See ANIMAL COMMUNITY COMMUNITY [J MA]

Bibliography J Braun Blanquet *Pflanzensoziologie* 1951 H Ellenberg *Grundlagen der Vegetationsgliederung* 1956

Plant disease

A great obstacle to the successful production of cultivated plants plant disease is also sometimes destructive in natural forests and grasslands Despite large expenditures for control measures diseases annually destroy close to 10% of the crop plants in the United States before and after harvest resulting in a financial loss of at least $3 000 000 000

Diseases may destroy plant parts outright by rotting or may cause stunting or other malformation Most diseases are caused by parasitic microscopic organisms such as bacteria fungi algae and nematodes or roundworms although a few are caused by parasitic higher plants such as dodder and mistletoe Many are caused by viruses and some are caused by poor soil conditions unfavorable weather or by harmful gases in the air

The living organisms and viruses which cause disease are called pathogens Most pathogens can multiply extremely rapidly the bacteria by simple division the fungi by producing spores which behave as seeds but are much smaller and simpler in structure Bacteria are about 0005 in long and fairly large fungus spores about 0001 in Virus particles are not visible with ordinary microscopes they can multiply a millionfold in a short time Roundworms reproduce by means of eggs

Most pathogens can be disseminated quickly and widely by wind water insects man and other animals They infect plants through wounds pores (stomata) or by penetrating plant surfaces Each kind of pathogen can attack only certain kinds of plants or plant parts Once inside the plant living pathogens obtain their nourishment from it in various ways destroying plant tissue or weakening the plant by robbing it of its food substances The rapidity of growth and reproduction of pathogens and of disease development varies with the kind of pathogen and host and with soil and weather conditions Some pathogens thrive best in hot weather others in cool weather Extensive and destructive epidemics develop when all conditions favor the most rapid development of the pathogen

Good cultural practices chemical disinfestation of planting material spraying or dusting with appropriate chemicals to protect against airborne infection and the use of resistant varieties are the principal control measures

Discussed in the following sections are the economic importance nature and causes of plant diseases the characteristic growth and reproduction of pathogens the infection stages and development of diseases the dissemination of pathogens and the diseases to which plants are subject in storage Discussion of other aspects can be found under separate titles or under the names of plants infected

Economic importance All plants and their parts are subject to diseases which may be caused at various stages of their life cycle not only by microorganisms but also by higher plants injurious salts in the soil and harmful gases in the air Diseases may rot the seed kill plants or make them poor and unsightly they may cause root rots stem cankers and rots leaf spots and blights blossom blights and fruit scabs molds spots and rots In transit and storage they cause rots of fleshy fruits and vegetables mold sickness of wheat rice corn and other grains and discoloration or rotting of wood and wood products

When weather favors their development some diseases become epidemic and ruin vast acreages of economically important plants The historic potato famine in Ireland in the 1840s resulting in the death of 1 000 000 people was due to epidemics of potato late blight Chestnut blight has ruined the chestnut forests of the United States Stem rust destroyed about 300 000 000 bushels of wheat in the United States and Canada in 1916 In the United States it destroyed 60% of the spring wheat in 1935 and 75% of the m[illegible] nt wheat and 25% of the spring bread wh[illegible] 953 a

g 7 -d fi cy d f g d b t ( ) t l f t th d ry mb l g (b) L b m t t d d d m t b d f th w t m l ted b t f m m ll d t rt d l i t l th t f th t l d t ll p f th t t t f m k rs (F m J C W lk Pl t P th l gy 2d ed M G w H ll 1957)

Fg 8 Bl kh rt f p t (F m J C W lk Pl t P th l gy M G w H ll 1950)

es m a q ed B pp r m g es m lybde m zs d th m l sed h m t m t th t th e ll d t l m t es f f th l tte m g t p l d m y e lt h dry t f t b g wh h d t b d fic y (F g 7) S PLA T N ER LS ESSE I L TO

F q tly d f es f m l t b d t m ed by l ly l e b the m l m y b p es t l m l mb t th t pl t t F mple, l l l h gh l m l f t i pr se t th sol pp bl q t tes (PLA T I I L LTR OF)

Bes des l m m t f m y th hem l m y be p es t th l d pl t d E f soil ll lt e lk l l d gg tes d ght d m g too m h t m y t m l t h rml g wth wl l es f l m y se ec d t t g l f ll h m l b la th l m y lso es lt i es d ty (l w pH) alkal ty (high pH) eith r f wh ch may inh b t normal pla t growth (e PLA T GROWTH)

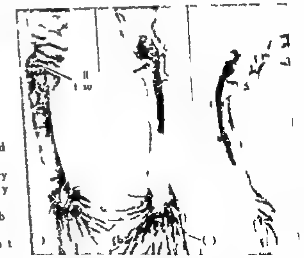
Th o l the p i c pal source of water which all pla t need in ary amo nt depe d ng pon the pe ie T o l ttle a a labl water l w g owth a d b l w c rta n l m ts r lts n wilti g Pl nts n e o e f m lim ted (trans e t) w lting but if it i prolo g d the affected p rt die (se PLANT WATER RELATIO S OF) E rgr e s a e ofte dam ag d by m tu e l s warm windy days in wi te wh n the o l s fr zen and th y c n t ab b s ffic t wat r to r pla e th l

Con ly too mu h wate the s il re ults in xygen defic n y wh h w ll cau e uffocation f the t u f o and ther und rgro nd pa ts of m st pl nt W t r h b ting pl nt u h a r ce a pt o E e wat r in th l f or e ta k nd f fu g s nd bacte ial d e and th s re often c f s d with the pur ly phy io l g eff ct of t much water

H gh l temperatu e du the growi g ea on m y l s d e for i st nce ntern l ec f p tat (F g 8)

The tru tu f il (p rti le i e a d rg n c c nt t) dete mi t wate h ld ap c ty d h nce aff cts b th the dit m t ed abo a d the as w th whi h plant r ts pe t te the l (ee SOIL)

W th r nd t Wind l ghtn g (F 9) d ha l m y i j re pla t d au t d ea ch a th ult ng f om unf bl tempe t (F g 10) Temp t effect ra ge f m



Fg 9 Light g i j ry f bb g l w k fi th i ry d ( ) C ll t th t m t th g d l wh th h g t d th pl t (b) l t f pl t h w ( ) Th p th wh by th h g p d th gh th rt d th l g d t Th p th w k ll d d th t ll p d d tt t f m d th ov ty ( ) D rm t b d t m l t d t g wth t l f j t b l w wh th h g t d (F m J C W lk Pl t Path l gy 2d d M G w-H ll 1957)

tures A bunch of small abnormal shoots is often referred to as a witches broom Underdevelopment or stunting may affect the entire plant or only certain of its parts

Chlorosis (lack of chlorophyll in varying degree) is the most common nonstructural evidence of disease For example in leaves it may occur in stripes or in irregular spots (mosaic) Various degrees of curling and crinkling of the foliage generally accompany chlorosis Sometimes there is also other abnormal coloration such as shades of red and brown

A number of diseases may cause similar symptoms These may be characteristic enough to permit diagnosis but often it is necessary to identify the causal organism for exact diagnosis

Causes of plant diseases Usually two or more causes operate simultaneously to produce plant disease For example if a parasite is involved the weather will influence the growth of the parasite as well as the plant s susceptibility to the parasite The following sub sections describe the influence on plant diseases of animals plants and viruses soil conditions weather agricultural practices industrial by products and plant metabolism

Animals plants and viruses Nematodes and insects are the animals that most commonly cause plant disease (Fig 4) Although herbivorous animals including many insects bite off and swallow plant parts the parts removed are not diseased and the animals are predators not pathogens However the loss of the parts eaten may cause the rest of the plant to become diseased Conversely some insects are true pathogens because they remain on or in the plant and cause disease symptoms typically associated with the insects involved Such

Fig 4 N m tod g lls c t d by *M l d gy e sp* ( ) On tomato (b) O p n p *(Aft Co a d J fl s f m J C Walker Pl t P th l gy 2d ed M G aw-H ll 1957)*

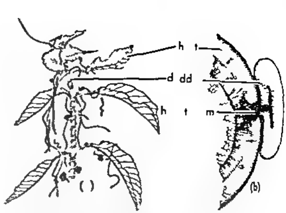


Fig 5 (a) Dodder attached to host (b) Section through host and showing haustorium of dodder extending into the host *(From F W Emerson B tany 2d ed Blakiston 1954)*

Fig 6 (a) Potassium-deficiency disease of cabbage (b) Iron-deficiency disease of cabbage (c) Manganese-deficiency disease of bean *(From J C Walker Plant Pathology 2d ed McGraw-Hill 1957)*

symptoms may include yellowing leaf curl and overgrowths Many nematodes are true parasites hence pathogens since they cause rot overgrowths and other plant abnormalities (see INSECTA NEMATODA)

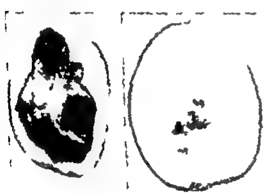
Certain algae fungi and bacteria are plant pathogens that cause disease Most plant diseases are due to fungi less than 200 are known to be caused by bacteria and even fewer are caused by algae and parasitic seed plants such as dodder and mistletoe (Fig 5)

Many plant diseases are caused by viruses which are neither plants nor animals but behave like living things in many ways and may properly be called pathogens (see PLANT VIRUS)

Soil conditions Deficiencies of mineral nutrients in the soil are a frequent cause of plant disease (Fig 6) Often the deficiency can be identified by characteristic plant symptoms For example yellowing of the leaf tip and midrib of corn indicates nitrogen deficiency yellowing of the margin potassium deficiency However the symptoms may vary somewhat in different plant species In addition deficiency diseases may be difficult to diagnose since they sometimes resemble those caused by viruses

Besides nitrogen potash and phosphorous which plants need in relatively large amounts smaller quantities of sulphur calcium and mag

g 7 B o-d F ty d se I g d n be t ( ) t m l s t t e t th e d ry e mb t g (b) L o be m t ted d d mo t b d f w t m l t d b t f m molt d t rt d l t ol co l th t lo of th oot d to ll pse of th o t t e t l m kers From J C W lk Pl t P th l gy 2d ed McG w H ll 1957)



Fg 8 Bl kh rt of p t t F m J C W lk Pl t P th l gy M G w H ll 1950)

es um qu ed Bo o ppe m ng ne e m lybd um z nc nd th e m l a u ed chemi t m nt tl t tl e alled t e l met H eve f of tl l tter m g a typ cal di e e m y ult l d y ot l t bag wh h d t bo n defi t ncy (F g 7) Se PLANT MINERALS ESSENTIAL TO

F qu ntly defi n of mi ral a t b d t rm ed by o l a ly al ne b u th mi e l m y be p e nt n hem l mbin t th t pl t a not e F r x mpl n fte n abl h gh l me il e f t p e ent tl so l ppr ec ble qu nt t e (P NT NU AL UTRITIO)

Bes d l m m t of many th h m l m be pr e t m th l a d au e pl t di E l bl lts au s lk l ju y d ggr t d ught damage t m h t g m y t m late ab o mal gr wth wh le x e of bo n m y au e ec nd tu t g U (o ab) hem l b l c th l may al ult e c s d ty (l w pH) lk l ty

(high pH) tl r f wl l ma t l f t n rt l pl t gr tl (s LEA F WELL)

Tl e e tl tl p inc pal so r f wat r wl i l tl pla t needs arying am nt depe l ng t n th pec es T l ttl a a l l wat r f [redacted] wl and bel w t l l e r s lt in w lt ng Plant c n rec v r fr m lim ted (tra nt) wilti g l t if it s pr l nged the affected p rt l (PLANT WATER RELATI ON) E ergree ar ft n l m aged l n t t re l n warm w l l y in w t r wl n tl soil s fr z n and tl y cann t al sorl uff ent water t r pl tl l

Co er ly t o mu l wat e In tl l resu lt in xygen d f t y wh h w ll a s uff e t n f tl t ues f root a l tl er underg u l part f m t plant Wat r l ald ng pl t cl a t are t pl Exces wat r in tl so l fa t r t t l l f fu gu an l la t i l d a l tl es a ft n nf d with tl p itely pl y l l ge ffect ft m l l wate

High al t mp ratur d ring tl gr w a so m y l en d e f l tan t t rnal n r t l pot t (Fig 8)

Tl tr t e l l (p rt l a l rganic nt nt) f t rm e at w ter l l ng a t and h n affect l th th n t t m t ed l a l tl a w th wl h gl t r t pe trat tl s l l SOIL)

F th f t a Wind l ghtning (Fig 9) and l a l m t jue e (la t a d se tr e d

l a tl es lt g f m unf ll t mper t es (Fig 10) T mpe atur ffect r ng f m

Fg 9 Light g i ry f e bb g ol w k fr th i j ry c ed ( ) C ll on th t m t th g o d l wh th h ge te d th plo t (b) t of pl t h w l ( ) Th p th wh by th ch g p d th o gh th ort d th vo c l g o d t Th p th wo k ll d d o th t ll p ed d t t o t fo m d t th ty ( ) Do m t b d t mul t d to g wth of l f s (st bel w wh th ch g t d (F m J C Walker Pl nt Path l gy 2d ed M G w H ll 1957)

tures A bunch of mall abnormal hoots is often referred to as a witches broom Underdevelopment or stunting may affe t the entire plant or only cer tain of its parts

Chlorosis (lack of chlorophyll in varying de gree) is the most common non tructural evidence of disease For example in leaves it may occur in tripes or in irregular pot (mosaic) Various de grees of curling and crinkling of the foliage gen erally accompany chlorosis Sometimes there is al o other abnormal coloration such as hades of red and brown

A number of diseases may cause similar symp toms These may be characteri tic enough to per mit diagnosi but often it is necessary to identify the causal organism for exact diagnosis

Causes of plant diseases Usually two or more cau s operate simultaneously to produce plant dis ea e For example if a parasite is involved the weather will influence the growth of the parasite as well as the plant s susceptibility to the parasite The following ub ections describe the influence on plant di eases of animals plants and viru es oil conditions weather agricultural practices in dustrial by products and plant metabolism

Animals plants and viruses Nematodes and in ects are the animals that most commonly cau e plant dis ase (Fig 4) Although herbivorous ani mals including many in ects bite off and swallow plant parts the parts removed are not di eased and the animal are predators not pathogens How ever the lo of the parts eaten may cause th rest of the plant to become di ea ed Conversely ome insects are true pathogens because they remain on or in the plant and cause disea e symptoms typi cally a sociated with the ins cts involved Such

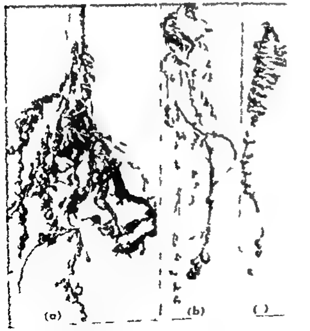


Fig 4 Nematode gall nc ted by Mel d gy p ( ) O tomato (b c) On par n p (Aft r C a d J ffe fr m J C Walk Plant Path l gy 2d d McG aw H ll 1957)

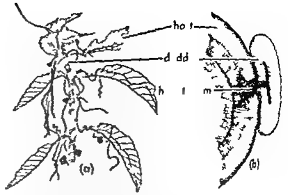


Fig 5 (a) Dodder attached to host (b) Sec n through host a d showi g hausto i m of dodde e tend ng nto the host (From F W Eme so B t B any 2d ed Blak ston 1954)

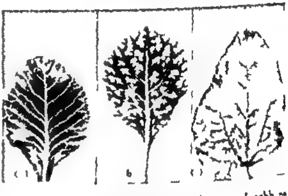


Fig 6 (a) Potassium-def ci ncy d sea e f cabb ge (b) Iron-def c ency d sease of cabbage (c) Mag esium d f ncy d sea e of bea (From J C Walker Plant Path logy 2d ed McG aw Hill 1957)

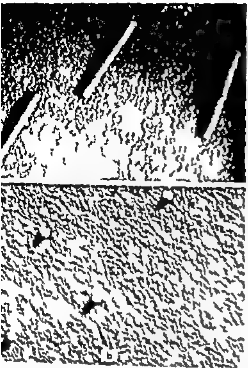
symptoms may include yellowing leaf curl and overgrowth Many nematod are true para i es hence path gen ince they cau e rot ove growths and other plant abnormalitie (see I ECTA NE IATODA)

Certain algae fungi and bacteria are plant path ogens that cau e disea e Most plant di ea es a due to fungi le than 200 are know n to l e cau ed l y bacteria and e en fewer are cau ed by algae and para tic eed plants uch a dodder and mistletoe (F g 5)

Many plant d ea es are caused l y iru es whi h are ne ther plants nor animal but l ehave like li ing thing in many ways and may properly be called path gens (PLANT VIRU)

S il conditions Defic encies of mineral nutri nt in the il are a frequent cause of plant di ease (Fig 6) Often the d fi ien y can l e identified b characteri ti plant sympto n For example yel lowing of the leaf ti and mid il f c rn indicate nitrogen defi iency yell wing of the marg n po i m defi ien v H w er the ympt m may va y somewhat in different plant pecie In addi tion def ciency di ea es may l e diff ult to d ag no e ince th y metime re eml le tho e caused by ru es

Be ide nit ogen pota h and pho phorous which plants need in relati ely large amounts maller q iant tie of ulpl ur calcium an



12 ( ) Rod-sh ped part les f th t bac o mo ru (b) P lyh d l p rt cl f th sq h m c El tr m g ph f p po t m d by fr -dry g t h q Mag fi tion of pp o t ly 100 000 (P I K b g f m J C W lk t P th l gy 2d d M G w-H ll 1957)

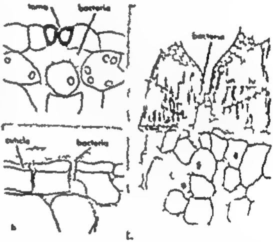
t pec l p bl m d h d r t n a a s f t an m o nd h t sympt m sed cl fy g nd am g th m

F ngi b t a a d a f w ed pl nt a h t it ph th t the l k hl ph ll d n e tly r d p de t d ect) d rectly pon n pl nt (t t ph) for ca bohydr tes (s IOTOSYNTHE IS) A m ls d some f ngi a d r ls dep nde t up the rg m t t u h m d nd tam u m t be m a nt m t p rt f th m l m ke p f th h t pl t (F g 12) Pl nt path g u lly p tr te t th h t t d g w w th betwee th ll ig 13) a all t llular d m f ed t ph m he pla t thog b te a s ally t ll l r th ylem (PLA T A ATO Y) F g mp sed f m p tubes alled hypha by n f wh h pl t p th g p e p e t r h t en th h r ll (F g 14) Th wd ry m ld w fu g gr w p e p lly ut d of pl t b t d pe t ab pt e o g (h s- ll l es of fu g l p od h u t th n ed pl t h m tlet d dod r ually p t at th h t by m a s f t lk rpt g n P th e ts d m d m y b wh lly w th th pla t th y m y

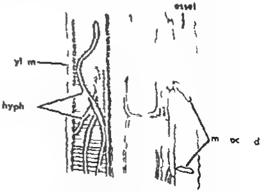
em t perfi t l an l pen t at th l t with pe t l zed m tl part

M t pl nt p th g n r p tes Some I n th ru t and p wd ry mil w are l l gat para tes that t e n gr w ly n a l t g l nt pl nt V r es a also in thi cat g r alth gh th y ar n t typ l rgani m Fu gi and l t t that a se nly n nl g f l t r es are alled sapr ph tes

M t f tl fu gi d ll p l nt patl g n l t ria an gr w n n nl ing org n c matt well a ra ti lly l t g matt r thes ar lled f c lt t e pr ph tes Som rg ni m l p ma tl a sapr ph ytes l t al ha tl l l t t para t w ak ed pl nt a d re tl ref r called fa ltat pa a tes Many pl t path g n h e both a pa a t (p th g n) a l p m phyt ph se f devel pm nt



F g 13 C mm ba t ial blight f be ( ) l n th gh t m t (b) l th gh fr t th l f th c tyledo ( ) l on of th eed th gh th t f th f l (Aft Z m y f m J C W lk Pl t P th l gy 2d d M G aw H ll 1957)



F g 14 Th c bb g y ll ws g m t o h f th bb g pl t N t f m t f m th l (Aft G lma f m J C W lk Pl t P th l gy 2d d M G w-H ll 1957)

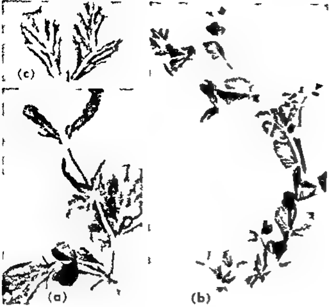


Fig 10 Freezing injury of pea Symptoms which are apparent several weeks after injury (a) Enlargement of the injured growing point (b) In the youngest leaf the stipules and the first pair of leaflets have assumed abnormal shapes and the second pair of leaflets did not form (b) Following killing of the growing point at the left a lower dormant bud grew out to form the main stem ( ) Necrotic band on a pair of leaflets which were developing at the time of injury (From J C Walker Plant Pathology 2d ed McGraw-Hill 1957)

poor development of plants grown in climates too cold or too warm to actual frost or heat damage For example tomatoes grow poorly and drop their blossoms in cool weather direct sunlight on the fruit may kill the tissue causing sunscald and the foliage is severely damaged by even light frosts that would not harm cabbage

Exposure to gradually decreasing temperatures in the autumn hardens perennial plants such as fruit trees against winter cold but exposure to the sun in the late winter may make the bark tender again This tissue is killed when it freezes at night causing another kind of sunscald

Although high temperatures may literally cook plant tissue with such results as heat canker of young flax and sunscald of tomato fruit the commonest effect is to increase water loss by transpiration resulting in drought damage Wind has the same effect the degree depending upon its velocity and relative humidity

In most green plants deficiency of light causes weak spindly growth and chlorosis although some species can endure much shade House plants are frequently affected in this manner but excess shading by buildings or other plants will produce the same effect out of doors

Agricultural practices Mismanagement of soil including untimely application of irrigation water and fertilizer can cause plant disease but other agricultural practices are frequently injurious The more common of these injuries result from the improper use of chemicals such as fungicides insecticides and herbicides (*see* AGRICULTURE FUNGISTAT AND FUNGICIDE HERBICIDE INSECTICIDE)

Nearly all fungicides are injurious to plants as well as to fungi although the damage to the plant is usually much less than the potential injury from the diseases controlled by the fungicides Examples of effects are increased transpiration caused by Bordeaux mixture on tomatoes russeting of fruit caused by lime sulphur on apples and yield reductions without visible symptoms caused by other chemicals Conversely the fungicide may contain a nutrient such as zinc that is deficient in the soil and much better growth of the plant may result

Chemicals used for seed treatment are frequently toxic especially to some species of plant For example plants of the cabbage family are stunted by copper containing seed treatment materials Vegetative organs like potato tubers are very susceptible to chemical injury and strong poisons like mercuric chloride often do more harm than good Materials applied to the soil to control fungi bacteria and nematodes may injure plants grown in the soil too soon after treatment

Some crop plants are very sensitive to herbicides being affected by very minute amounts of such things as 2 4 D (2 4 dichlorophenoxyacetic acid) Tomatoes may be affected from sources far removed Symptoms of 2 4-D are sometimes confused with those of virus diseases

Industrial by products The fumes from ore smelters frequently cause widespread symptoms of plant disease including stunting yellowing and necrosis Where atmospheric inversion layers prevent their escape even traffic and domestic fumes may be toxic (*see* ATMOSPHERIC POLLUTION)

Plant metabolism products Brown areas on stored apples (scald) may be caused by ethylene gas produced by the apples (Fig 11) This gas occurs in small quantities in many healthy plant tissues but is produced in greater amount by diseased and aging cells Ethylene gas may also cause yellowing in plants and it accelerates ripening in certain fruits such as banana (*see* PLANT METABOLISM)

PLANT DISEASE PATHOGENS

Most pathogens are grouped primarily on the basis of their structure but bacteria being morphologically simple are classified to a considerable extent by physiological character Viruses repre-

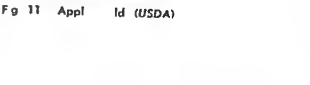
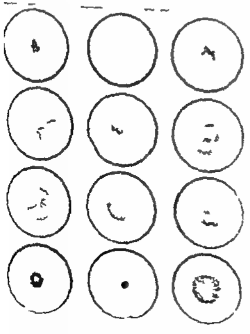


Fig 11 Apple scald (USDA)

a d reprod ct re be t d t rm ned ly arys g th ompe t n f nth t media St d es n th ffects f tempe at re l g l t and tl r nmen f t r a e fac lt ted wl en rg m m ca l m on c lt med a Alth ugl all p tl g n n m h m r q r m t s mm n d ff gr atl t pec l req i m nt l t tl n fi al med a and h t pl t B gr w ng h g n rt fi ll m l s l arned at t tl m h enables the des l pm nt f bett r t l es

I t s l t u f b r a d f g Am ng app m t l 150 pec es f patl g n l and tl e m ny th a l f f gı th r ar d ff nces w th respe t t tl ki l f pl nt l pla t p rt h k th n g w Fl t *I mp a l) g* nl n ıld nd lt ed fi pa ag t *(I t ıa sp g ı pall* a p agu *nth m n mp* the ba t i m wh h a ses ll k r t f th g c l fl a d l t l pl nt par ti es mb f th mu ta d f m ly ly On tl e tl d th f gu *Rh t s l a* r ol t pot t alf lf l a d hı dred f th r ec es n ma y d ff e t pl nt fam l es the fa m *Ag b t m t m f* es r n l n g ap r pbe rv hry a th m m nd nı s th r pl t th b t um *F u a* es ft ot f alm t all k nd f fresl getables



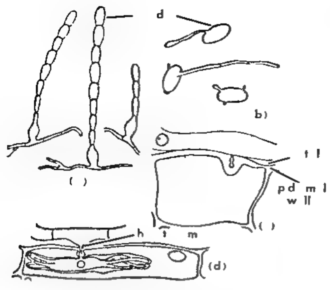
g 16 Eff t f t mp ff t m l f m t (Ud) g m yd) d ff b lty f l t g w t th m ( ) l W V A8–3–1 t m d t (b) WV A8–5–4 g w ly t ll t th m ( ) l W V A8–5–2 1 g w f ly w ll) C (U ıv M Ag E p St T h B ll 65)

Som patl g ttack nly a f w pla t p a t r t ies tl r atta k ma S m att k t nly tl r att t m th r ca l af pet anl till tl r att k fruit Som att k ng t ies ll r tta k ll nes Tl r ar f es f y th and f age f h rl eou pla t anl f wo l pla t Som patl g n it r ll pl nt p rt f use pull h t t all t gre ıf les l y me t T unf rt n f a f tr l tl n m f e f tl u a d f kin l f gl t it ı neces s ry t l arn th n f t n ın f r wh f a h patl g thri es

F t nm t l fa t Tl rat anl kın l of g wth n l e prod ti f patl g n ar ffect l by n tr ti n m it r t mpe t (Fig 16) l ght th a ıd ty a lkal nity f th medi m tl r l t am u t f ygen an l a bon l ıl anl ly ther mi r rg m with wl ı h th y mu t m pete M t p th g n requ r free m ı tu f r germ nati n a l nfecti alth ugh som p w l ry m ld w g rm n t t lry r S l m t re sometimes t d t rm ı g f t r ın gr wıth a l r p l t S m g th g tl t l e tl w ll th best at l gh m t r nt t w m at l w T mpe t d t rmines tl ge g gl l l a so l oc r n f mans l a m e tl ar l l t mper tu th mi ım m pt m m anl m m m ff f l ff nt p th g ns Th pe l l f l f ng th pot t f t l light f ng ı a f y ll w r t f wl t des l p best t r l at l l w t mp t r th pe h l r wn t f g th pott lt nd l wn r t la t ri m and t m u t f h t des l p best at a r lati ely h gh t mp ti Light h les ı fl nce th n t m p at on th th f p th g n m t r l ıt t t gl ff t prod t f w m f ıng S m w l g m u h th potat l la t ri m l k a alk l n th gh pH) l w m l a th t h g l l root f g ı l k a l w l (l w pH)

I p d t n of b r a d f g A l r a ı n w k w g l nt p tl g l ters r p l t f mpl f gl l te m l ıl ı t th ı t l nd A d n m y u e y 0 t 30 minutes a gl l t ri m ll y d p g n f 300 000 000 000 witl 24 h Tl t h eve rıes w th tl kı l f f a t r m w th t n tr t n w tl r per t e l w th tl nm t l nd ti

M t fu g h we r rep od l th ll a l ally l m f tl em x l p l t r lt n ap d m lt pl t (F g 17) wh x l prod ti n lt ı tl p od t n f p es th t nfa al l d t l g l fu g t ı t g w a d pro d a xu l po wh le th m nt f ble and nut t e tly a a l bl b ıt tl ey t nd t p d c x l p r wl gro tl ı check d ff n x lly p od d dı p (m er p r) f wl at t m t (I o g m t ıt) an nfe t n th lt g my el um g w f r t m d th n f rm a pu t l nta n 50 to 400 000 w d n e



Fg 15 E ys phe ▪ om n s (a) Co d opho e and c d a (spores) (b) Germ at ng con d a ( ) P et a t on of cut cle a d ep d mal wall (d) Hausto m (a B aft Reed c d afte G Sm th f m J C Walk - Pla t Path l gy 2d d McGraw H ll 1957)

Symbiotic relations of organisms Para iti m is the one of a erie of a ociations characterized by intimate physical union of taxonomically dissimi lar organism Such relationships are known as symbiosi and may be neutral beneficial or harm ful to the symbionts An as ociation such as that of legumes and nodule bacteria beneficial to both part ners is called mutualistic symbiosis Parasitism is antagonistic symbiosis

There are different degrees of parasitism In the early tages the association between rust fungi and their ho ts may appear to be almost neutral harming the plants little Other fungi such as tho e rotting fruit can become establi hed only in dead ti ue producing enzyme or toxins that kill adja cent li ing cells which they then inhabit Some biologists ay that such organi m are aprophytes not para ites because they never colonize living ho t ti ue But the term parasiti m is generally u ed to refer to a relation hip with the host plant a a whole becau ▪ the degree of intimate relation hip i often difficult t determine

Ecologic relations of organisms As ociations of organi m in the ame enviro ment w thout phy ical union are called ecologic and are often ery important in plant disea ▪ (*see* ECOLOGY) As in ymbi i the effects may l e l enef cial ne tral or harmful Metal io i occurs when one organi m u e a ı b tance for food and produce a by prod uct that enal le another t grow If the b efit a e recipr cal the relation hip is called ynergi m as when the f ıngu *Mi cor rama nianus* pr d ce py rimidine and *Rhodotori la rul ra* a non porulating yea t make tl iazole (*see* CRYPTOCOCCALES PHY COMYCETES) Tl e e chemical are compo ents of tl iamine which l oth organi m need but whi h nei tl er can produce alone If deleteriou ul tance (antibiotic) are produced the relation hip is called antil io i

All of the ▪ relation hips may be important to the urvival of certain plant patho en especiall ome of tho e which live in the oil part of the time Metabiotic and synergi tic relation hip ma help them to survive antagoni tic relation hips will hinder survival One of the goal of the pla t pathologist is to encourage antibio i that will eliminate certain oil inhabiting patho en

Ecologic as ociations may exist between t o or more pathogens inhabiting the ame ho t plant a i common environment When fire bli ht bacteria parasitize apple twigs and permit the entrance of canker and wood rotting fungi the relation hip be tween the bacteria and the fungi is metabiotic Th molds *Oospora citri aurantii* and *Penicillium d tatum* can rot fruit more rapidly together than ei ther can alone This is synergi m Anta oni m seems to exist between races of the potato la e blight fungus and one will replace the other hen they parasitize a potato plant together

Even the relationship of ho t and patho en ma be ecologic at first For example *Rhi octo a solani* in the oil cau es visible injury to the root of oybean before touching them Accordingl the fungus is at first antibiotic to oybean later it be comes parasitic and pathogenic [C.J.E.]

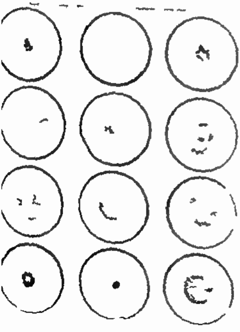
Growth and reproduction Many plant patho gen especially among the bacteria fungi and viruses can multiply with amazing rapidity under fa orable conditions Viru es although not gener ally considered living organi ms may increa e a millionfold a few days after introduction into the right place in the right kind of living plant when temperature and other environmental condition are favorable to the virus

Food requirements of bacteria and fungi Al though lack of chlorophyll prevents the ▪ organ i ms from using olar energy in ynthe ize ba ic arbohydrate from carl on dioxide and water a green plant do their ba ic nutrient requirement ar ▪ entially the ame as tho e of higher plant Tl ey require carl on hydrogen oxygen nitrogen ph phoru and sulf ır a tructural element In addition they need the metallic element pota i im magne um iron zinc copper calcium gal lium mangane e molyl denum anadium and candi m Pota ium and magne ium needed in elati ely large am unt are de ignated macroel ment the other ome of which are needed in m nute mount are often de ignated microel ment Vitam ns enzyme and hormone are al n ed d f r g owth and reproducti n

F r experimental purj ▪ pure cultures of fac i ltati e apr phyte are grown in the lab ratory on terilized ynthetic med a containing sugar or ome othe ur e of carl on alt of the other nec e ary element and ▪ ent al vitamin f r those org ni m whi h cannot ynth e i e th ir wn Natu ral plant p od ict uch a p tato l roth steamed c rnm al or oatmeal often are ı ed a nutr ent l a e Liq id med a a e u f r me purposes for other tl e nutrient oluti n are lid h gelat n or agar N tri eme t

and rep oduct ar best det mi ed l y ary m the c mpo t on f ntl eti med a Stud n tl effects of tempe at ir l ght n l th r en i nmen t l f t n e f lt ted h n rgan m can l gr n n lt med Alth gh all pati g n rgan m have som requirem nt m c mm n d ffer gr tly n pec l r q ir m nt l tl i al med and n h t pla t By gr w ng n art fi i lly m l i lea ned ho t tl m h e ables th de el pm nt f bett nt l e

o t l t ty of l ct i n d f g Am g app m t ly 150 pec es f p tl g n l and the many th i nd f f m th a d ff es w th espect t th k nd f pl nt plant p rt h h th y e gr w Fla t l mp a l l gr w nly w ld a d lt d ff x a parag r t (P et a ja ag i pall a pa m l th m n mp th ha t m wl i h a ses ll k r t f age a l ff a f r f ted plant par t l f th mu tard fam ly nly On tl th d the f g Rh t a s l es m t t otatoes If lfa, cl er and hu dred f th tes t ma d ff e t pl t f m l es th l a m Ag ta t m tum f t n a es wn gr p pbe ry h y th mum and nu th r pl nt th b t um E u ta e a soft r t f lm t ll k d f fles tables



16 Eff t f t mp t e f g wh f t m to r l f o m t (U r l g m yd) t dff b l ty f l t g w r th m ( ) r W V A8–3–1 t m d t (b) W V A8 5–4 g w sc ly t ll ot th m ( ) l W V A8–5–2 l g w f ly w ll t C (U M Ag E p St J k B ll 65)

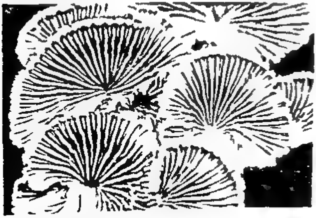
S ne path g n atta k ly a f w plant p rt r ti es th r atta k n any S m atta k r t only oth att ck t m th r e se l af p t and till th r att k fr t S me atta k ung tis sues th r tta k ll ne Th r are d a es f y th a d f ag f f rl eo t plant an l f w ody plant S me path g n para iti all pl t p rt f ptill h t at all tag f l les l p m nt T le ta l n l e ntr l tl n im t l s a es f tl i and f k l f plant it i neces ary t l arn th e n l t n u l r wh h a l path g n thri es

F ur nm tal f t s The rat a l kin l f gr wth and r pr l ti n f p tl g n ar affected l y nutrit n m ti t mper tur (Fig 16) l ght th a l lt alk l ity f th med m th r latt am unt f xygen an l art l x l an l l y ther m r rg ni m wit wh l tl y m t r m pete Most path g n t jut free m ture f r ge m n t n an l i fecti n alt l gl som g w l ry mild ws an g rm n t in dry ir S il m t re som t mes i a d t rmining fa t r in gr wth and r p l ti n S m path g tl r l t tl w l tl t be t at l gl m i t i nt nt som at l w T mpe t ir d t rm es th geograph al a d sonal oc urr n f m ny l ases n tl ar l nal t mpe t r tl minim m ptim m f m x m m d ff r f rd ff e t p th g Th p a l l f l f gu th pot t late l light fung i nd ll w u t f wh t fer l p le t at a r l tr l y l w t mpe t r e th pea h l r wn r t f n gu th pot t wilt a d l r wn r t l t m and t m u t f wh t dev l p best at a r l t ly l gl t mp tu e Light h les influ th an t m p at r n th gr wtl f path g n t n tu l t t l ngl affect produ ti n f some f ngi S m soil rganism s h a th potat sc l l act rum l k n ik l n tl gl pll i l som l th ll g l l root fung l k an l soil tl w pH

l p du t n of ba t a a d fung A f r a n w k w pl nt p th g t tua r p l nt l mpl f i ngl t t r m di i l t t ? tl t t 4 d o n A d t n may y 0 t 30 m nut a ngl l t um o ll pr l a p g ny f 300 000 000 000 will 24 h u Th r t h we r ar es with tl k d f l t m th u n t t n w th t mp r t d th th e m t l n i t M t f n h we r r p l t l tl ll and u lly l m n f th m a x l rep l t n e lt r p d multipl ati n (F g 17) wh a xu l r p d t ult in tl p od t r nl l le d t In g ne al f gi t n t g w a d po d a u l sp wl l tl nm t f hl a d n t nt a l a ilabl l ut the t l t p du l n whe g th i che ked Th a x lly p od ed ur d p e (mm p re) f l t t m t (P cin gr m nts r t c) n u nfect th ult g m el m g w f t me d the f rm a p t l nt i ng 50 to 400 000 n w u ed po

Fg 17 Spo e prod c ng bra he of *Pe ll um* sim lar to the one f om wh ch the d g p c ll is ob ta ed Cha s of spo s a p oduced on th ends of branches (*U M Ag E p Sta*)

The time required ■ only about a week at 75 F but it increases to a month at 50 and even longer a temperature decreases Each new pore can cau ■ a new infection and this process continues at a rate that varies greatly with temperature moisture and light until the wheat starts to ripen or growth is otherwise checked Then the winter spores (teliospores) are produced the e differ from urediospores in appearance and cannot nor mally germinate until they ha e been expo ed to winter weather The apple cab fungus (*I enturia inaequalis*) may produce many succe si e crops of asexual spores (conidia) on the fruit and lea es during the growing eason But it does not pro duce sexual spores until the following spring on infected leaves that have fallen to the ground the previous autumn Some fungi such as the erg t fun gus (*Claviceps purpurea*) produce sclerotia bodie made up of den ely interwoven hyphae which may survive winters or other unfavorable c nditions and then produce fruiting tructures under appropriate conditions in the spring



Fg 18 F u t bod s of a t e hab t g m h o m *Sch zophyll m* Bas d ospores a p od ced o th des of th g ll F *S h z phyll m* the g lls a pl t le gthw s dry weathe th y l p a d o con ■ l a d protect the rf ce wh ch po s ar bo e (*U M Ag E p St*)

Special stimuli are ometimes nece sary to in ate the formation of fruit bodie (Fi 18) so fungi require the stimulus of light for fructifi tion although they grow well in darkne e require special temperature others require certain nutrients or vitamins

How where when and the rate at which fur grow and reproduce depend on their inheritance and their environment The inheritance determ the limits within which the behavior of each k d of fungus can vary and the environment determines its behavior under particular combinations of con ditions [E.C.S.]

INFECTION AND DEVELOPMENT OF DISEASE

Infection of plants by a patho en terminates a series of ■ents that begins with inoculati ■ which is the contact of a su ceptible part of a plant b the inoculum Inoculum is any infectiou part of the pathogen such as pore bacterial cell and virus particles Typically inoculation i follo ed by entrance into the ho t and infection follo en trance A plant is infected when the pathogen tarts taking nouri hment from it

The time between inoculation and infecti n is the incubation period Becau ■ it i often d fficult to tell when infection occurs the incubati n per od is usually counted as the time between inoculation and the appearance of the fir t symptoms of infec tion

The probability that infection will follo inocu lat on depends upon the vigor of the inoculum the duration of favorable environmental cond tions a d the re i tance of the ho t (*see* PLANT DI EA E CO TROL) U ually only a mall part of the inoculum produced reaches a su ceptible plant and onl a mall fraction infects the plant Con equently most plant pathogens survive and are de tructi e partl becau e they produce fanta tically large amount of inoculum

The inoculum Inoculum of viru e and bacteria consists of the individual virus particles or bac terial cell re pecti ely the inoculum of fungi ma be p re pie es of hyphae or pecialized stru ture such as clerotia Pathogenic plant like d dder produce true eed and nematodes pr d ce eggs b th of wh ch function as inoculum

Bacteria and iru es produce bill ons of cell or virus particles in infected plant and each ne t nit the retically can infect another plant Fungi pr duce spo es on the urface of hyphal gro th r in a ariety of specialized tructures which ma l l rge a the giant puffball ■ almo t in i ll t th unaided eye (Fig 19) Some of the pore pr duc ng tructures functi n o er a con iderable peri d f time and like bacteria produce prod giou amounts of inoculum

B cteria and viru es are omewhat re tricted a pathoge l y ha ing no special mean of liberat ing them el e fr m the h t alth ugh the bacteria m y o ze o it in ticky droplet For d eminat or transmi i n the e pathog n depend ch e upon plant ■ ntact i e man althou h

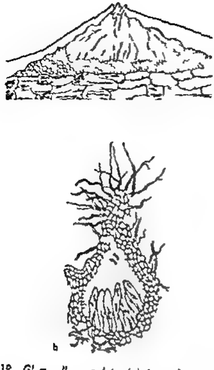


Fig 19 Gl m ll g l t ( ) Ac rv l s o oppl lru t (b) P th m From J C W lk Pl t P th l gy d M G w-H ll 1957)

i r m y be p tt ed h rt d) t l ra n Some f g p od pores n t k ma l k b t l oo d r d m t d n m l th sam a) ba t Oth r fu gi ha wa t l be te r f c blv ject p es) i th) wl r they n b ed b the wind Th g es f n gu p th g th potent al f mu h f rth r a d fa t pr ad th n th b et o alth ugh th i rr al n pt bl plant s mu h m re a m tte l ha th f t rry th noc l m b e t ft k im l r pl t f r food (Di em t s de ed g at d tail lat ect f th a t le)

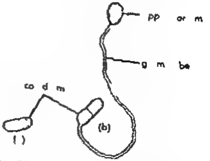
D rma t oc lum e f the m t mpo ta t but n t th l an by wh h pl t p th g n u e d g f od l p a tı l f im po bl If th path g n w thı p al host t ally q t d r g th e t p od f th ho t S l t s nd n the eg tat h ph f m fu g may rv e p r od f dr ght nd ld i dep d ntly f th h t Oth tho- g q th p tect n f th d d h t plant n t so u h g t ld d d ought a ag n t a t g n t g m (EC LO IC IN ERAC TIONS) Th pec lly tru f pl t path g b r f f h h rv e l g f s par t d f m h t t s Some l o ly m tes t fr m the l ng f t th r l k tob c m r m u f t f ye s n dr ed l a

At th b g n ng f th g ow ng s th fir t n lum f a p thog s all d p mary noc lum th t wl h r p d c d l t n i fe t d plants ec n l ry nocul m Th primary i oc l im f fu g m ber tı g pe es ll rsı ng l y pha r s ler tı fı n the l ypha r scl r tıa p d c pores wl i l fı t n a prim ry inocu l m

Ma fung pr lu t r m r ki f f pores Th l rmed late ı tl gr wing as n (resting pores) u ı ll will n t g m nat t l aft r a pe r l f d m n and w ll rvı m re r ll l dr ght tlan pores p lıced l rı g tl gr ıng a Some l k th p es f tl all g el l ot fungi anl tl chl m d ı r of th nı n m t f tay d rmant f r es ral year th a r g th pecies f es al if se ı t ll l ast a e n t g n n tl l nl f r es ral as n Su h di a es at ffe ft t e tr l l y r p t ta tı n

R peat ng p es typ ally re m rpl l gi lly l t t fr m tl rest pores anl ar pro- d l gre t mber n l ed pla t lu ing tl gr wı g sn Th u all g rminate r p lly whe es r n ı m tal d t ar fa rall B f g rmı t n r pe t ng pores an ury l ı tı l rang ng fr m sev r l l ur t se ral week d pen l g upon tl pe es Th d ı r m nes l tg l h w l r a l u d r w lat l tı n p tl g n tl pread l r ng tl g w g as

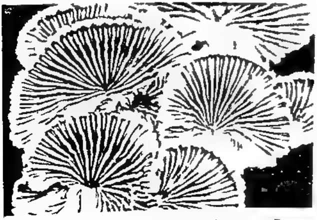
Spore germination (min tı a applied ı po es r eed m a th esumpt n l eg ta t gr wtl l l ng t tf des l pment f a new d l al l f (gt th ı lly m a th pro- d tı f a hypha alled a g rm t be (Fig 20) Cell d a f l r ra nd tl l t l g f n ma tod and ect egg re mpa alle proces es so f r th t fı n t n p th g n t on rned (rm tı iccur tf th pore ı t d rmant a d tf en r m nt l fı n are fa r l l Tl u lly q a rt temperat e rang a d l q d w t r ltl gl a few pecies f *f ngi* (po de y m ld wa) g rm n t ı l mid a r Ce tai pec es l eq r tl pres n e f food ı l tan es pec al t m l nt a soc ated w h *the* h t al f nh b t r that m y l produ ed by th p th g tai deg f a l ty S h r qui eme t l mit g m at *n* but m y be l efit t th pe es Fo ampl tl nee ty



Fg 20 Gl m ll g l t ( ) C d m (sp) (b) C d m th t h b om sept f d g g m o- t pp m t s p f g m t b (F m J C W lk Pl t P *bol gy 2d d* M G w-H ll 1957)

Fg 17 Spo e p oducing b anch s of Pe ll m s m la to th e from which th drug p cill n ob ta ned Cha n of p es a p od ed on the nds of b a he (U M Ag E p Sta)

The time required is only about a week at 75 F but it increases to a month at 50 and e en longer as temperature decreases Each new spore can cause a new infection and this proce continues at a rate that varies greatly with temperature moisture and light until the wheat starts to ripen or gro th is otherwise checked Then the winter spores (teliospores) are produced these differ from uredio pores in appearance and cannot nor mally germinate until they ha e been expo ed to winter weather The apple scab fungus (*Venturia inaequalis*) may produce many uccessive crop of asexual spores (conidia) on the fruit and leaves during the growing sea on But it does not pro duce sexual spore until the following spring on infected lea es that have fallen to the ground the previous autumn Some fungi such as the ergot fun gus (*Claviceps purpurea*) produce clerotia bod es made up of densely interwoven hyphae which may survive winters or other unfavorable conditions and then produce fruiting structure under appropriate conditions in the spring



Fg 18 F t bod f a t ee hab t ng m m Sch phyll m B d osp r a p od d o the de of th g lls I S h phyllum the g ll pl t le gthw e dry weathe they c l and co c al a d p ote t th rfac o wh h spo s a e bo n (U M Agr E p Sta)

Special timuli are ometime ne es ary to in ate the formation of fruit bodies (Fi 18) so e fungi require the stimulus of li ht for fructifi tion although they grow well in darkness e require special temperature others require certain nutrients or vitamins

How where when and the rate at which fungi grow and reproduce depend on their inheritance and their environment The inheritance determines the limits within which the behavior of each kind of fungus can vary and the environment determ its behavior under particular combinations of con ditions [E.C S]

INFECTION AND DEVELOPMENT OF DISEASE

Infection of plants by a pathogen terminates a series of events that begins with inoculation which is the contact of a su ceptible part of a plant b the inoculum Inoculum i any infectious part of the pathogen such as spore bacterial cell a d virus particles Typically inoculation i f llo ed by entrance into the ho t and infection follo s en trance A plant is infected when the patho en start taking nourishment from it

The time between inoculation and infection is the incubation period Becau it is often diffi ult to tell hen infection occurs the incubation period is usually counted as the time between inoculati n and the appearance of the first symptom of infec tion

The probability that infection will follow inocu lation depend upon the vigor of the inoculum the duration of favorable environmental conditions and tl e re istance of the ho t (see PLANT DI EA E CON TROL) Usually only a mall part of the inoculum produced reaches a su ceptible plant and only a mall fraction infects the plant Con equently m st plant pathogens survive and are de tructi e partl because they produce fantastically large amount of inoculum

The inoculum Inoculum of viru and bacteria con ists of the individual irus particle or bac te ial cell respecti ely the inoculum of fungi ma be spores pieces of hyphae or specialized truc tu es s ich as clerotia Pathogenic plant l ke d dder produce true seed and nematode produce egg both of whicl function as inoc ilum

Bacteria and iru produce billion of cell r iru part cle in infected plant and each new nit the retically can infect another plant Fungi produce p e on the urface of hyphal gro th or n a variety of speci li ed tructures which ma be la ge n tl e giant puffball or alm t in i ll to the unaided eye (Fig 19) Some of the pore producing structures function o er a con iderabl period of time and l ke bacteria produce prod gi u am unt of inoculum

Bacteria and iruses a e somewhat re tricted a pathogen by having n special mean of l berat i g them el e from tl e h t alth ugh the bacteria may ooz out in ticky droplet For di emination or tran mi o tl e e path gens depend ch efl upon plant c ntact man alth

ath r h wever e ften les important th n e a t mb n t n f weath r at crit l t mes ms n t m t l f ctor that de t m t fr m e opt mum lim t th de l pme t f a d eae

Eff t of t mp r t Temp r t re ha a maj r ject n d d l pment and d termi es th a nal and egi nal n iden e of m t d ea e ampl a u on f d a e atta k e r i n eping b nt g es n g ll g eens i n th rn U ited St t n w m ld or r b eath melt w n wi ter red thread d r ng the moder te t mp at res f pr g a d fall d llar pot r ng the warm t mperatures of early nd l t mm r a d br wn pat h du ng the h t we the t m d umm r The fu g a ing thes d ea es n y atta k th f a es gr t t the c own f the pl nt nd m y k ll th pl nt tt lv n p t l e f h t t ze f r e ch d sea e Thes d es p od mila ffect b t tempe at r d t mt h a h d t m t destru tive The length of t ib ti n period of di ase i g e ed by p l ng t mp atu Many d e es t h a u t m ld w a d leaf spot nl mall l i n abo e gr und plant pa t The d m g to the pla t d pe d n th n mbe f le t n whi h tu n dep d th number of d cy l Th lap ed time fr m infecti n t po e prodi t o —th le gth l th e bati n pe d—d t rm e the f q f d a les Th s t mp at e f n d t rm ne hether path oge a p od n gh d ea e y lea f de l pm t f n p d m Tempe tu l k w se m y fl n the ympt m expres n Th ympt m f ma y ru d d pp a e m ked t h gh tempe tu es Tempe t also de t rm es wh ther erta whe t tie a u pt bl t t t e rta p ra t r es f t m ri t Th ff t f t mp ature n d a e de l pm nt m y b pri p lly o the p th ge r t m be n th f t Wh n th a d nal t mpe a t e th ame t gr wth f the p th gen ult d fo de el pm nt f th d e th f fect p p ll th p th g n Howeve whe th ptim m t mpe t f gr wth f the p tho g n ult e diff s f m th t f ma im m d de l pm nt th t mp r t e p babl p d p th h t pl nt by w ke g t

Eff t f l ght L ht ff t d a e developm t p lly by t ff t ph t thes a d th m l t p s of th ll t Of l g t pa a t h t a d p wd y m ldew g ne ll des l p h t he m l t n m x m l al th gh th es ty f the d les d b m p th g n n me h t ma b de ed t h gh l ght t es Low l ght ft we ke s pla t d th g ed p e th m t d e d b f lt apt pl yt

Eff t f mo tu e M tu m g f t gr at d tr f p th g nto th h t Th m t tu qu r m t f th t bl hed p th g uppl d b the h t an th m t e l e (w t b rpt o p t) of th h g ph f th p th g lw y g at th th t of the para ti ed h t ll Tran pirati n (wat r ap l) fr m di a ed al e g u f j l nt g rt s great r than that f h althy p rt Th w ter e n m f the h t i d rupted in wilt d a ly the ff t f the path g n n tl tra locati n f water in tl xyl m and th m ti permeabil ity f l l ag pare hyma and in r t l a l tle d tr cti n f tl ti ues f r w t r al pti n n l c n l t Tl rat of ympt m devel pm nt and d th f the plant ti u i w it and r xt r t a e elerated by e ces i ely l w atm gl ric h m d t es and l w l m i ture a l l l ty

R l t n f ol Soil rea ti n a r g r l l y hro g i n ntrati n affect tl dev l jm t f many d es in th il l otat scal les ame in a tl l (bel w pH 5) whi l ll g l l root i n t so es ve in les acid s l ( ) pH 5 7) H w r the ext t t wi l tl soil s t n affect the i fecti ity f thes path g n a d tl ubseq t dev l pment f th disea es l n t bee d t rmined A tl l y h g n i n c n ntr ti n f th plant ll t e latt ely n t nt despit d fferen es in the ra g f s l re ti s il pH pr l lly affect d se se level pm t in l ectl y n ffect the a il l il ty t the ho t r path ge of m e l n triti nal elem t in tl soil

Soil xyg and arbon d e le c ncentrati n ffect the devel pm nt f root disea Th ffect n infect ity of th g th g pred po it n f th l t n f n di ea e dev l pm nt ha n t l een d u p ied alth gl th d l jm t f the host s m ad e ely affected l y h gh arbon di oxid nd l w oxygen t n n in the soil tl n f th gr wth f ma y f ng l p th g n

Eff ct of tr t The ffect f nutri nt ar l rgely d ect in e pl nt and tl ir path g eq re the a m es t al m al lem t How ev tl a al l e am nt f ea h r r l lem nt a d the balan e b tween th m ffect the struct re a d phy l gy of the h t an l th may be e th r fav rabl e unf abl t the devel jme t of dil f re t p th gen Tl p n ipal min ral l ment t f rtil (n tr g ph ph ru p ta m and al um) h ve th m t p un d ffect D a s ed by bl g te p ra tes u h a rut p wd y m ldew a d m y vir es dev l p be t n norm l g la t h v ng pt m l m e al tr n wh le ub orm l plant dev l j m nt due t nad q m r u l alan ed m n r l n tri fa the devel pm nt of ma y d es ucl a root t th t ar ca d by fa ultat e pr pl t S m cula p thogen are aff t d d rectly l y th on e trat n f n g mpo nd in the du t t ues of the h t

Plant disease epidemics Ep d mic f pl t d e ur wh n a high p rcentag f the ho t p p l t n rta n a i ff ct d w th ul fi nt eve ty t l n r e th r g th ury t l or p prod ct on A pid mi t th culmi ati n of ll v t ll t ng the i it t a d dev l p me t f a d th ugh tl ter cti n of th g eti n tit t n f h t and p th g w th the n l n onmental fa to Th d l pm t of

for a host stimulant will prevent wastage of spores in the absence of the host

When a nondormant spore is placed under favor able conditions germination may follow in 45 min utes or only after several days depending upon the species age of the spores and variations in the environment Since conditions change rapidly ger mination is a critical time for a fungus because if it does not penetrate the host quickly the germ tube may be killed especially by dryness It is at this stage that fungi are most easily killed by fun gicides

Establishment in the host For bacteria and viruses entering a host is a passive process Bac teria accidentally get into injuries or are put there by insects or other agencies they may also be drawn by water into tomata hydathodes or nec taries Viruses often are placed in the host by in sects but many can be transmitted when the sap from infected plants comes in contact with minute wounds in healthy plants

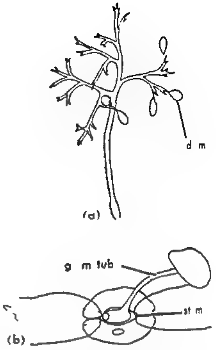
Spores of fungi may also be carried into plants by various agencies but many species have active means of penetration the method usually being characteristic of the species In some germ tubes enter stomata by producing a flat structure (ap pressorium) over the stoma from which a hypha grows through the opening (Fig 21) Others ig nore the stomata instead the appressorium adheres to the cuticle of the plant and forces a slender in fection peg directly through the protecti e layer (Fig 22) This apparently is accomplished entirely by pressure as no enzyme action has been demon strated

Animal pathogens like nematodes have special mouth parts that pierce the plant and the nema tode may remain external or it may actually enter the plant

Even after penetration pathogens may fail to in fect due to the presence of mechanical barriers lack of proper nutrients or the presence of inhib iting toxic substances These factors depend not only on specific interactions between host and pathogen but also upon the environment Success ful establishment of the pathogen may mean kill ing the ho t cells and living up n the dead ti sue with or without the actual penetration of living cells [C J E]

Development within the host After a pathogen has become established in a susceptible host the rate of disease development under favorable condi tions follows a sigmoid (s shaped) curve with three major aspects (1) the lag phase or incubation pe riod when infection is not e ident externally (2) the exponential pha e when the pathogen spreads rapidly in host tissues and symptoms and signs of disease appear and (3) the enescence phase when limiting mechanisms of either host or patho gen re trict further extension

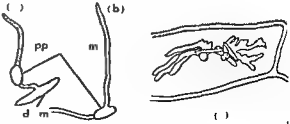
Disease development varies with genetic suscep tibility of the ho t genetic aggres i eness of the pathogen and with many en ironmental factors that influence the host the pathogen and the inter



Fg 21 *Pe o ospora dest ctor (a) C n d opho b ar ng co d a (b) Conid um germ nat ng by a germ tube the latter pe t ati g stoma (From J C Walk r Plant Pathology 2d ed M G aw-H ll 1957)*

actions between the two Environmental factors in fluence the growth rates and the metaboli m of the host and the pathogen and the interrelati ns be tween these activities determine the pattern of d ease de elopment Furthermore the effects of past en ironmental conditions on the host may affect disease development a condition known as predi position when host susceptibility is increa ed The combined effects of these factors on growth a d development of healthy crop plants in nature are poorly understood and the problem becomes in creasingly complex when the plants become di eased

Climate often determines the adaptability of plant species to geographic areas and may also de termine the geographic distribution of their di eases For each disease there are minimum opti mum and maximum values for each criti al en i ronmental factor The mean measurements of



Fg 22 *C ll t t h m c o (a) Co d um h h h m at d o d f med opp m which t t n ha g m ated (b) Ge m at g app sso m ( ) C n d o o d app o la o th s fac of the host o d th s bc t c l myc l m de el p g afte p t at (F om J C Walk Pla t P thol gy 2d ed M G w-H ll 1957)*

d p b t th d m nati n f pl t g th f ng by th s me l l l ttle m est ed *Septo a* a d *Ph m* both f wh l a e a lt t de of plant di ea es, prod ice con dia in a ky mat x tth p d (f t g bodies) I t weather th p es e o t te dr l Sp es *S pt a a icol* wh h es a leaf d a f l gle f p e k t be pread locall pl h g ra d p d p e umably m t p s f both *S pt* d *Ph m* ar p d m y b p e d fa ther tha l c ll ance o f *Phoma* f eq tly ar f d i ratl g mle t th air Th d emi t f ese d m lar f g h mb at f r i d d des ri es m t d

Dissemination by insects M ny of the m t t t e d f ec m plant p d h efly ls by ts, especiall le f pp d ph d (e He ipte a) Eff t e p d lly i l m ted t th d tan the ect fly b t oc lly the i ect fected ttl he ma be ed ma m l by th wi d Bl t f f t ees d Dutch lm d ea oth d by pecies f *C t t m ll* e ar ed f m f ted t h lthy tree by l rk beetles Th beetl ocul te h lthy trees w th th f m the f ad a d k ll the trees th th tre ded by g e t ml s f th b k beetles h h b ed de th ba k W th t th b tles th f g ld t b ll t l d mi ated d w th t th f g the le tl w ld d ltl d m g d l th a t n d h lthy t ee y umber

I sects l e p bl f d el pm nt f p d m f g t ld gr a d lti ted l P m ry fect f th fl w f thes pl t by *Cl p p p* by w d bo e (Asco ix TES) Th pr m y fec t lly ry l ht, b t w th f w d th f ted fl p d l mb f d t d t ky fl d The fl d tt t t n m ll fles wh h w ll w the p es the t th fl d d th f t L k w p p es f m y t f g e ded m t tt t t fles wh h ry th p f m p m t th d e f rt l t f th t f g R tly g f u g l m th d m t h b f d t ly t rry l m f f g th t e de t t f t ed gr b t lso t th m t t t f th gr d th bl th f g t g w f t d m d m g (F g 24)

D sseminat on by other animals *E d th* t th f g th t h t t bl ght carr d by w dp k d ly m ll p f th f g h b w hed f m th f t f gl b d Th w dp k p b bly t ly p d th f g l ll b t lso t b t d th m g t t th p d rth th p d f th d t t d It t k w wh th m y b d th l l fl ghts l g d t

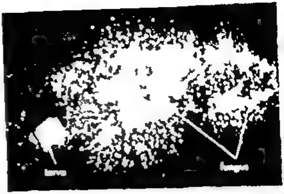


Fig 24 F gi th t use d t o to f sto d g g ow g f m l rv f g i f t g i se t Th larv wo f d f ct d to k ll i oc l m th ts d f it body Se l p of A p g ll g wi g o t f om th int io f th l t

m g ati r g larly arry spo es f g l nt p tho g and d mi t th m ffecti l l t t eem h ghly pr lall Th t f l ird tod t an l th r animal in th loc l a l l g d tan l t at n f g l nt p th g n req res m re i t g t n

Dissemination by man M n ha bee r pon i l f r rap d a l wi lesp l l m nat n f m f the m t destr ti f es f h eco mi pl ts Bef e the mmu ll r nt g u ture f m y g l t d es wa d sc red about 1850 th g d wa h l ted a l t m t t x salle F n tod y wil r g t pec t n f pl nt m t r al mm r nd ev r re t ct n th h pm t f m ny pl nt a d pl nt p t di em t n f pl t p th g n by m a t by me l m ted nd g f l ly will nt n t be la ge fa t t w t l l gr lt e f r ma y r t e m A f w mples g ped a d ng t th u l ag t f th d a ill trate th at r of h pr ad th d mag th t m l e ed a d me f th d ff ult es inv l ed in l alt g r d t g p ead f pla t d es l y ma

F us d ses Comm t f gr wer f pot t es t the th rn Un t d St tes ally l ta n the tock f eed r pl nt g tul f m th th rn t t s ch fly be u f the d ff ulty f p od g f e ed t k n th South B t f r m y ye r th q l ty f ed p t t es g w n th N th w s e r t c m l ts we e h l in fect d w th m t di es th t gr atly d d th y ld f th r p g wn fr m l t ck S c b t 1920 e d e t fi at n d pa t m t h b tabl hed i th rth rn t t th t pr d ed p tat F ld l p t t re m ed e l times d g th n l y m p te t p t and t h s tested i th gr h d g th w nt t u e th t n de tect bl l d d th d t k S m h p t t s X p d e ymp t m m t and m y b d l g th w th t d t t n S ch wl en p d

epidemics requires (1) abundant viable inoculum of a virulent physiologic race of the pathogen disseminated widely and rapidly at the proper times (2) dense and extensive populations of a susceptible host in a receptive stage of development and (3) optimal conditions of the environmental factors affecting production and germination of inoculum penetration of the host by the pathogen and rapidity of disease development Generally epidemics develop from successive cycles of dissemination inoculation infection growth and multiplication of the pathogen as all requirements rarely are fulfilled simultaneously

These interrelations were illustrated by the progression of an artificially induced epidemic of black stem rust in a field of Marquis wheat at St Paul Minn in 1956 (see Fig 23) The epidemic was initiated by inoculation with urediospores (summer spores) carried in oil Inoculations of the wheat June 13 and 15 resulted in an initial incidence on June 23 of 15 to 20 pustules per stem which was sufficient for abundant dissemination and inoculation of the wheat for favorable infection periods associated with heavy rain June 25 and lighter precipitation June 30 and July 1 Pustules from secondary infections were maturing by July 4 and an epidemic developed rapidly resulting in completely diseased wheat within the following two weeks

[J B R]

DISSEMINATION OF PLANT PATHOGENS

Effective dissemination of pathogens requires that the inoculum be carried in viable condition to host plants that are susceptible to infection and that the conditions at the time favor germination of the inoculum and infection of the host plants Knowledge of the means of dissemination of a given

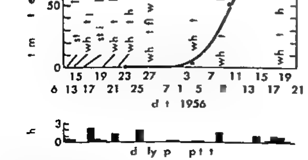


Fig 23 Development of an epidemic of stem rust on Marquis wheat (From J B Rowell and ... Olien ... of wheat with ... of P ... Phytopathology 47(11) 689–690 1957)

pathogen often is basic to control of the disease or diseases it causes

Dissemination by wind Spores are discharged into the air or picked up by even the lightest of air currents and carried by chance to susceptible hosts sometimes only to nearby plants sometimes for hundreds of miles

Local dissemination The conidia (spores) or sporangia of many of the downy mildew fungi are produced only at night or during periods of fog or drizzly weather They are very sensitive to drying and to sunlight and usually can be effectively disseminated for only short distances A single maize plant infected with *Sclerospora philippinensis* is estimated to produce from 1 000 000 000 to more than 5 000 000 000 spores of the fungus in a single night Given a succession of nights favorable for production spread and infection local epidemics of this and similar diseases can build up rapidly

The fungus *Cronartium ribicola* which causes white pine blister rust can spread from wild currant plants (*Ribes*) to pines only by means of basidiospores which are small delicate and short lived The basidiospores from wild currants cannot be disseminated effectively more than 900 ft If a stand of white pines is free from blister rust it is necessary only to eliminate the *Ribes* bushes in the stand and up to 900 ft away to completely protect the pine from blister rust in the future Many of the most valuable stands of white pines have been protected in this way

The fungus *Ustilago tritici* which causes loose smut of wheat produces powdery masses of chlamydospores that replace the floral parts of infected plants These spores are produced at the time the noninfected plants in the same field are producing their flowers The wind carries the spores to flowers of adjacent plants and thus spreads infection locally Although the spores can be carried long distances in viable condition the short flowering period of the host plant ordinarily precludes effective *long distance dissemination* The same pattern is followed by a number of other loose smut fungi and the use of smut free seed which eliminates inoculum from a given field or area ordinarily is sufficient to protect the crops against these diseases

Long distance dissemination East of the Rocky Mountains a more or less continuous belt of wheat is grown from northern Mexico to central Canada and the wheat matures progressively from south to north In many years epidemics of stem rust of wheat propagated by repeating urediospores of *Puccinia graminis* var *tritici* strike wheat in northern Mexico and southern Texas The spores are carried northward by the wind sometimes in huge local advances sometimes in hordes that infect wheat plants over an area of several hundred thousand square miles Essentially the same course of events prevails with this disease in India and in portions of Russia

Dissemination by water A number of saprophytic fungi are well adapted to spread by splash

ing d p b t th d emin t of pl nt path g f ngi by th mea h b en little t e ti *S pt ri* d *F hom* both f whi h c u e a m lt tud f pl nt di e p du n dia n t ky m t w tl pycn d a (f it g l od es) I t we tl e the po es o e o t te dr l Spo es f *S pt e la* wh h a le f d ea f y g l gl af pi e k wn t b p ad locall pl h ra d p d p esum bly m t pe- es f b th *S pt* a d *Ph ma* a e p e d Th y may be p ead farth th locally i po e f *Phoma* f q tly a fo d i r th l ge n mb i the a r The d em ati n of th e d m l f g by omb at f r a d w d de-erves mo t dy

Dissemination by insects Many of th m t d tru t e d f c m pla t are p d h fly nly by i t espec all l f pp d aph d (s e HEMIPTERA) Effect e p e d us lly l m ted t th d ta the in t c fly b t c lly th ect nfected w th th m y b a ed m y m le ly th wi d Bl est f fe tree d D tch lm d ea both ed by pec es f *C at st m ll r* r ed f m nf t d t he lthy trees by b k *beetles* Th beetl oc lat h lthy t ees w th th f n g s th fu g ad d k ll th t ees th n th t ees n ded by g te mb f th bark be tl h h b ed d r th ba k W th t th b tle the f ng ld t be effect ely d em ted d w th t th f gu tl be tl w d l ttl dam g s d a ly th y t n d h lthy t ees ny umb

I ects a e l p ble f d el pm t f p d m f e g t w ld g d lu ted l Pr mary f ct n f th fl w f these pl t by *Cl* p p pu ly w d b as- (As o tYC TE) Th p m v s fe t lly i y l ght, l t w thi a f w d y the infected fl w r p du la g umbe s of d we t d ti ky fl d Th fl d tt i t mall fl wh h wall w n the p th t th fl w d so sp d th fect L ke w e py n p f m y t f d d a m t tt a t t fl es whi h ry th po f m py m to n th a d u e f t l t f th *ust* f Rec tly gr lest ng w ev l m th nd t s h be f u d t o ly t rry lum f fu g th t u de- m t e t t f th g d th bl th f g t g w f t d u m e d m g (F g 24)

Dissemination by other animals *E d th p ast* th f th t u e hest t bl ht i ca ed b d p ke d ly a m ll n p f th f g ha b w h d f m th f t f gl b d Th w d p ke p b bly n t o ly p d th f g l lly l t l nt b ted th i m gr t t th p d o th so th p d f th s d t t d It n t k wn wh th m n b d th loc l fl ght l g d t e

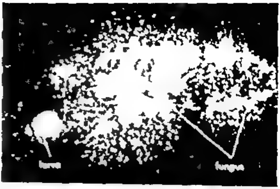


Fig 24 F g th t c d t t f t ed g gow g f m o l rv f o g f t g se t Th lorv w fo d f t d t k ll i oc l m th n d f it body S l p c es f A pe gill g w g o t f m the l t f th i sect

m g at r g larly rry pores f pl nt pathogens and d m t th m effect ly l t it eem h ghly pr bal le Th r l f bird rod t d th n m l i the local d l g di t n e di m i t f pl nt path g s requires m r invest g ti n

Dissemination by man M l lee respo i *ble f r p d* and w despre d d minati f som of the m t destr ti e d e es f h eer mic pla t B f re the mmu c l l nt gi n *tu e f* many plant d a es w d sc e ed al t 1850 th pr ad w hil ted a d t me t nt exc sable F tod y with rig i per t f plant m te l n mm r d ere r t t the h pm t f many pl t and pl t p *rt* d mi ati f pl t path g n by man i by n m a el mi ted and p l bly w ll e t t be l f ct w rld g ult r f r m ny y t m A few amples g uped c d g t th a l ge t f th d ea llu t t the at f pr d th d mag that may l au ed nd some f th d ffic lt es i l ed i halt ng r ed ad f pl nt d ea es l m

f us d as s Comm al g ow s f p t t es n th thern U ted St te u ally ol t i th t k of eed pla t ng t b r f m the th rn t tes ch fly b u e of th d ffic lty f p od n v s fre d tock i the South B t f r m y ye rs th q al ty f ed p t t g w i th N th w er t s m lot w he ily n f ted with o m e us d i es th t g e tl red ed th y eld f the p g wn f m h t ck Si abo t 1920 ed rt ficat n dep m t t ha b en t bl h d n th th t t th t p d ed p t t es F ld f pot t es r e m ed ev al t mes d r g th ea by m p t t i p ct a d tubers test d in th g h d g th w t t r th t d t tabl u i l ded th ed tock Som v ru es h s p tat u X p du symp- t m me ar t es d m y b arr ed long th with ut d t t S h v r wh p ad

epidemics requires (1) abundant viable inoculum of a virulent physiologic race of the pathogen disseminated widely and rapidly at the proper times (2) dense and extensive populations of a susceptible host in a receptive stage of development and (3) optimal conditions of the environmental factors affecting production and germination of inoculum penetration of the host by the pathogen and rapidity of disease development Generally epidemics develop from successive cycles of dissemination inoculation infection growth and multiplication of the pathogen as all requirements rarely are fulfilled simultaneously

These interrelations were illustrated by the progression of an artificially induced epidemic of black stem ru t in a field of Marquis wheat at St Paul Minn in 1956 (see Fig 23) The epidemic was initiated by inoculation with urediospores (summer spores) carried in oil Inoculations of the wheat June 13 and 15 resulted in an initial incidence on June 23 of 15 to 20 pustules per stem which was sufficient for abundant dissemination and inoculation of the wheat for favorable infection periods as ociated with heavy rain June 25 and lighter precipitation June 30 and July 1 Pustules from secondary infections were maturing by July 4 and an epidemic developed rapidly resulting in completely diseased wheat within the following two weeks

[J B R]

DISSEMINATION OF PLANT PATHOGENS

Effective dissemination of pathogens requires that the inoculum be carried in viable condition to host plants that are susceptible to infection and that the conditions at the time favor germination of the inoculum and infection of the host plants Knowledge of the means of dissemination of a gi en

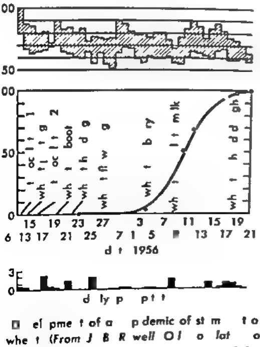


Fig 23 el pme t of a p demic of st m t o Marq s whe t (From J B R well O l o lat of wh t w th spo of Puc a g m a t t c Phyt pathol gy 47(11) 689–690 1957)

pathogen often is basic to control of the disease or disea es it cau es

Dissemination by wind Spores are discharged into the air or picked up by even the lightest of air currents and carried by chance to susceptible hosts sometime only to nearby plant sometimes for hundreds of miles

Local dissemination The conidia (spores) or sporangia of many of the downy mildew fungi are produced only at night or during periods of foggy or drizzly weather They are very sen itive to drying and to sunlight and usually can be effectively disseminated for only short di tances A single maize plant infected with *Sclerospora philippinensis* is e timated to produce from 1 000 000 000 to more than 5 000 000 000 spore of the fungus in a single night Given a succession of nights fa orable for production spread and infection local epidemics of this and similar disea es can build up rapidly

The fungus *Cronartium ribicola* which causes white pine blister ru t can spread from wild currant plants (*Ribes*) to pines only by means of basidio pores which are mall delicate and short lived The basidiospores from wild currants cannot be disseminated effectively more than 900 ft. If a stand of white pines is free from bli ter ru t, it is necessary only to eliminate the *Ribes* bu hes within the stand and up to 900 ft away to completely protect the pine from blister ru t in the future Many of the most valuable stands of white pines have been protected in this way

The fungus *Ustilago tritici* which cau es loose smut of wheat produces powdery ma e of chlamydospores that replace the floral part of infected plants These spore are produced at the time the noninfected plants in the ame field are producing their flower The wind carries the spores to flowers of adjacent plants and thus spreads infection locally Although the spores can be carried long distance in viable condition the hort flowering period of the host plant ordinarily precludes effective long distance di semination The ame pattern is foll wed by a number of other loo e mut fungi and the u e of smut free eed which eliminates inoculum fr m a gi en field or area ordinarily is sufficient to protect the crop against the e d eases

Long distance dissemination Ea t of the Rocky M untains a more or le c ntinuous belt of wheat is grown fr m northern Mexico to central Canada and the wheat matures progres i ely from south to n rth In many years epidemic of tem ru t of wheat propagated by repeating uredio p res of *Puccinia graminis* ar t itici trike wheat in n rthern Mexico and outhern Texas The pores are ca ried northward by the wind sometime in short l cal ad ance ometime in hor le that infect wh at plant over an area f se eral hundred th usa d s are mile F entially the same course of e nt pr ail with th di ea e in India and in port n of R i ia

Dissemination by water A number of saprophytic fungi are well adapted to spread by plash

Fg 25 A d m g d g f wh t f m o mm l t g b wth A p gl (f g) g w g f m th g m (mbry) App m t ly 250 000 b h l f wh t th b w ff t d wth l of m re th $240 000

t h m d t e d wn t 0° The result ng d te n r t o may n t be d t ted unt l m t f th d m ge ha bee d n Re e ch s gr d ll mak t g labl t me t the g a tr de f t and p ples th t w ll ble th m t ed e u h l

[C M CH]

B bl g aphy F C Bawde *Pla t V us d V us D e* 3d ed ev 19 0 C M Ch t n *m Th Mo d d M n* 1951 E (a m nn *The F g* 1952 V G l lly d H L Ba ett *Phy l gy f the Fu g* 1951 E C St km n nd J G Ha r *P pl f Pl nt P th l gy* 1957 J C W lke *Pla t P th l gy* 2d ed 19 7

Plant disease control

Contr l f pl nt d by ltu l m thod h m l t t plant a t d t on of p th g n nd q ti es F ert d a e the m th d mu t b omb d t g e eff ct e t l

Cultural practices C ltu l pr t m y e t l pla t d by l m t ng ed ng the ff t n f th p th g by alt r ng th su pt b l ty f th h t pl t Th s t do by t ll ge m th ds f fert l p t t nd r a t ry p t s d g ed t elim n te

ource of infecti n *Se* AGRICULTURAL OIL AND CROP PRACTICES

Som path g i v e r p r d ie l it are ineffecti e f l iri d l y pl wing f r ampl the cereal l ead bl ght f ng c rn Oth r s ich a the cabbag l la k rot l act ria l e ver winter but will die ut in a f w year if a i ceptil le cr p i n t gr wn wl e e tl ey ccu r C p r tat n fertili ati n and the gr wing f c rta n cr p will en ou age the e tal l hment f rgani ms in th o l that de tr y c rtain path gen l y ntil i for mple the c tt n root r t rgan m whi l i red i ed by lil ral appl ati n l man r S FER TILIZING SOIL MICROORGANI MS

C lt vat n to elim nat wee l and variati n in depth and t me f planting lso red l e from ce t i di e S metim uniqu tillage meth od a e emj loyed uch a fl od ng field with wa t to destr the l an na wilt rg ni m Ex or d fi i n ie f both maj r and m r el ments n fert l er an a e d r in r a e u cep tib lity of plant S e PLANT MINERALS T EN TIAL TO

San tary p a ti i h l an ng nd di in fecti g of farm qu pment and d tr y ng f cr p res dues ha bo ing path ge ften l lp i control pe fic d e es

[H D T]

Control with chemicals Ch mi al are u f t p e ent t reduc the er ty f l n mal ha ge in pl nt i d ed by path g ni o gani m o bv ad e n v r m ntal ndit

E te l pl t p ot ti n Va i chem al s b tan a e appl ed t th fa s f growing plant e th r t d t y uperfi i lly gr wi g pl nt path g n t p ot t ag n t nf t u mat rial th t m ght ub eq tly be dep sited on the ur fa by w nd w te and i ect (e IN ECTA) Th u f in t d s t cl d d am ng external prote t b au e t i di ea of pla t re mm nly tr n m tted by n ects S INSECTICIDE PL T VIRUS

E tern l p tectants m y b ppl ed t f l ag b anche t m oot eed e m l t ll tul rs nd i pagati g tock th fo m of p) du ts d p ak or lurr e Sp ys ar aqueou l t o a n lly oil u pe i n of fung dal li te i d l c mpo ds appl d with app opri ate a h n (se FUNGISTAT AND FU GI IDE) F quentl rfa e te n d p s nts a d dl e e a dd d to liq d sp a) to imp o age a d p l ng adh nce to pl t arfa (Fig 1) El bor t pray s h d l s ha e bee d el ped t n d q at pr tecti n n t ch impo ta t d a e pple b l te blight of p t t leaf pot f b a s nd bla k pot of (PLANT DI FA E) D t ar dry form l t n f fu gicide b i d nd i t d s wh h a e bl wn nt pl nts f om gro d eq pment or f m a pla s but at t me d t re p ferr d f t e e of ha dl ng a d n s t ati s wl e ght nd a l w t r mp t nt f ct Du t ar sp

to other varieties may cause considerable damage All of the more than 50 known virus diseases of the common potato probably have been spread throughout the world by the shipment of diseased tubers Similarly virus diseases of stone and citrus fruits probably have been carried to all parts of the world where these crops are grown by shipment of diseased grafting stock Sometimes these diseases do not produce any obvious symptoms until the trees are several years old Special techniques are required to insure that grafting stock of material for clonal propagation such as cuttings is free of hidden viruses that may greatly reduce the productiveness of the future crop

Bacterial diseases Ring rot of potatoes caused by *Corynebacterium sepedonicum* is spread chiefly by knives used to cut potatoes into pieces for planting and by contact of cut seed pieces or bruised whole potatoes with sacks bins or machinery contaminated with the bacteria This disease was spread throughout the world by the shipment of infected potato tubers A few infected tubers in a lot of many bushels may furnish sufficient inoculum to infect a large proportion of the seed pieces cut from these tubers drastically reducing the yield of the crop grown from them A somewhat similar bacterial disease of geraniums is spread chiefly by knives used to make cuttings for propagation by the resultant contamination of soil pots and other equipment and by the hands and clothing of workers Constant strict inspection and sanitation are required to keep these diseases in check Citrus canker caused by *Xanthomonas citri* was introduced from the Orient into Florida about 1910 apparently on diseased planting stock and threatened to destroy the entire citrus industry there It finally was eliminated by eradicating some 15 000 000 trees a drastic costly but necessary measure

Fungus diseases Late blight of potatoes was carried from South America to and throughout Europe by the transport of diseased potato tubers and later it was carried from Europe to North America Both powdery and downy mildews of grapes endemic on wild grapes in America were carried by man to France on grape stocks imported to obtain new varieties They quickly spread over Europe for a time threatened the survival of the extensive grape and wine industries and still add greatly to the cost of production

White pine blister rust native to Siberia was carried into Europe on pines imported for growing in botanical gardens About 1900 this disease was carried to the United States from Europe on infected seedling pines and now is found throughout the major white pine regions of North America The Dutch elm disease was introduced into the United States from Europe about 1930 It has spread as far west as Wisconsin and has almost eliminated street plantings of elm in many eastern cities A somewhat unusual case of plant disease being spread by man is that of a disfiguring and sometimes fatal canker of sycamore caused by a species of *Ceratostomella* This fungus was f d to be spread almost entirely by means of pores in a wound dressing applied to the wood exposed when branches were cut off The wound dressing was supposed to be fungicidal but actually served as an effective carrier of the inoculum of this fungus

Nematode diseases Although the evidence is largely circumstantial it is likely that some of the most destructive plant parasitic nematodes have been imported into the United States in contaminated plant materials

PLANT DISEASES IN STORAGE

Tubers fruits and fresh vegetables are subject to spoilage by a variety of pathogenic and nonpathogenic agents during storage and transit and often this hazard remains acute up to the time of consumption Seeds such as those of wheat corn barley soybeans and flax which often are stored in bulk for months or years also are subject to deterioration At times the losses in transit and storage equal those occurring while the plant are growing In general storage diseases are divided into those caused by nonpathogenic factors and those caused by living organisms or pathogens

Nonpathogenic storage diseases Fruits and vegetables in storage suffer from a number of serious nonpathogenic or physiological diseases Typically these show up as discolored spots or areas on the surface of or within the affected part sometimes accompanied by collapse of the tissue leaving pits on the surface or hollows within These diseases are caused mainly by an excess of gas such as certain esters or carbon dioxide given off by the fruits or vegetables themselves or by chemicals introduced into the storage rooms These diseases may be controlled by maintaining proper storage conditions including temperature humidity and aeration Fruits vegetables and seed harbor abundant microflora and damage beginning from nonpathogenic causes may be increased greatly by subsequent invasion of the tissue by bacteria and fungi able to cause rapid decay

Pathogenic storage diseases Common fungi such as *Botrytis Penicillium Rhizopus* and *Sclerotinia* invade and rot many fruits and vegetables Losses up to 25% of a shipment between harvest and consumption are common in fruits such as oranges apples peaches pears and plums and vegetables such as potatoes sweet potatoes tomatoes and peppers Bacteria or a combination of fungi and bacteria often rot stored potatoes and root vegetables These diseases may be controlled by harvesting only sound disease free produce careful handling to prevent bruising the use of clean containers maintenance of low (about 40 F) temperature in transit and storage and at times the use of fungicide

Grains stored in bulk are subject to in a n a number of fungi principally those in the gen *Aspergillus* (Fig 25) which have the ability to grow at moisture contents in equilibrium with r

te fr ed m fr m a path g and a d e rep- e ts ab l t i t ce In mo t pla t h w t ther v y n degr e of resi t nce aller an imm ty Som ar eties f wh at and p ta e ha nb ti f ha a te that p tect iem f i ly well under m ny e diti n in th field ga t t m t nd late bl ght r p t ly Th n al d k d f re t ce not yet mpletely nd tood s alled ad lt pl t es ta e ma i pla t re i t nce o fi ld r tan e Hyper en t ty also ha th pra t al effect e f a gh de e f res ta lth gh it actually i a upe ept bil ty wh h res lt n the dden ath f th fi t f w ell atta ked b t e tabl he ond t n whi h the rema n g ho t c lls are ote ted f m nt n ng att k

Gen re p ble for r ta ha be n deter n ed d t l d me a nd the i h it f th tant eter ha l n t d d A led m a t g n nt ol t p A r tance to y llow abbag At lea t f r d m ant ma r g e all d d f m S l m demiss m on t l l te bl ght t e n pot t and th re is som de e th t or tw th r m j r g n exi t Ma y th (m d fy ng o pe l ap mu g l r i l d the fi ld e ta ce to pot t lat bl ght wh b a v tv atta ked by th path ge b t pr d ce n pt ble r p l e th d m fr m th tta k ld m ev e Th a e g n n fla th t g ern tan to th a io l fla st d rresp d ngly th re g that g e n ul n th ra e f th fl t f u

R t attrib t s S m m t g t ek the r so t r a r ly es ta e ly n the i mpat b lit s f th tw a t d m t h l t m th t f the h t t a d th r f the l p th e Oth w k r ga d ntr bu t s t es ta ll f ty h t rs o ttr l t th t h lp to w d off r t d ntry f p th g t t o b h i p th g s p g es w th th tv o t lly de t y the m d

C rt n r t nt rete d p s f pl nt h gl tt ib t that thwart p t l path g t tta k oth ha m y tt b tes pl y g f f y mp ta e a th n tr b te to th ty s t n t a pe fi p th g n A th k t gh p derm m j e t i r t p t t P l g d l e f t m t t m ly m ll t m t m b the w f m p th g th t rm lly t thes t al p n ng f a pl t O a lly a tomat l e figu t n th t t f w th fo m t on et at d t ty f w t r film l le p th g n Le t f w th mp t ll ga t a d w th ap ity f ap d b zat n f ll ta d the d C ll ll w th m h d fibe th e d y th k n g fi mpe l th d a e f ng hyph a d l fi d c ll w ll m b p bl b t r f me p th g fi d t th l d pl nt t W t labl t m l d ff g f m m pl t t t nt the r

und ng l or wat r are t xi t path g n a d nh bit their wth Alkal i t xic t tain r t r t gan m ar mp n nt f me re i t ant ar eties and tr ng a id an l volatile l fid re th pt te t e ch mie l in th r Ph n l c ompound ch as tan in atech l and chl g n c a i l ar oft n mor al i tant in r i tant var eties tha t e ptible r ets and alth gh me phen li s l tan es may l l ind in th ho t cell in n nl th al f m th er a e th r f rm f th se mp u d wh h a ecti ly t xic t p th g

I tatt n t s tanc A simple an l g n ral xpla ti n f re i tan e n t p ll A ar et with resi ta ce t one k nd f path g n i n t eces rily re tant to ther p th g that t lly att k that plant D ff nt va ties and spe e f pla t may ffer fr m n l a r fr m ral d e and th u and f path gen par t c lar l th e am ng th f ng l ct r and nem tod au vari u ki d f di a e in plant (s Nematodes) Th rea ti n f a i ty t one d a e may be ndep dent of t r t i al th r di a F r xampl th wh t ety That h wa alued f r it t m t e tan e n th 1950 l t it la k ade t r t a e l leaf r t eal and oot t

A r ta t ar ty m y n t l r t nt t all r pr entati f ne path g n l t a a gl pe es of a c op pla t ft n e mpr e many agr n m o h rti ult ral vari t es o may a n gl p e f p th g mp e ev al a i t es d alm t i um al le t ar r ra es th t d ffer t ally phys ol g ally and in pathoge i c pabil ti e th gh th y l ok uff i ntly alik to l rec g ed and la fied a th ingl p r Th ph l g ap l z t n i t n e ral p th h s m y f the real r t the l t bl ght Phyt phtho the w lt Fu ia the oot tt g Rh ct the h an m a the s l m and th g b et e lyt p virus Th ph n m n p b bl i of m re gen al eu e than h s bee de on trated and wh ever it i t e mpli t s r p imp ment d the br d g f new d a re tant ar t e In m n t th s tan e of any ar ty m t b n d ed i lat t an nd dual r e t r f p ll path g n

E m nt l f t E tern l fa t s fr qu tly ha g th qu l t l a d a r t on T mp t l ght n t e ts (l th m) d m n l m t l a b n d x d c n ntrati a d hyd g n nt at n (a d ty) may eff t ha ge S metim the ha e ar l ght m tum t m A notabl xampl f the l tte mm n n m f th wh t f m Keny a d in m f th a n f o t The l n v be h gh ly es ta t t d d al f tem t at on t mp at a d pt ble to the am r if the t mp t nly 15 F h ghe Thu the i t e f a a ety f equ ntly m t be d d l t to ce f p th g n i l o n I t a

Fig 1 Chemical control of potato late blight Toluca Valley Mexico (Rockefeller Foundation)

cially important in the treatment of seed prior to planting or for the control of seedling blight and rot Soaks and dips are solutions or suspensions of toxic compounds in which roots corms bulbs and other vegetative plant parts are dipped for varying periods of time for disinfestation or for the control of specific diseases Slurries are liquid seed treatments consisting of a milky suspension of chemical dusts in water

Internal plant protection This includes the correction of physiologic diseases arising from deficiencies of essential nutrient elements in crop soils and the use of systemic (internal) fungicides and bactericides Deficiency symptoms indicate the lack of major or minor nutrient such as nitrogen phosphorus potassium sulfur boron iron manganese zinc copper and molybdenum Deficiencies in major elements are readily corrected by the application of commercial fertilizers and in microelements by the application of appropriate compounds to the soil as foliage sprays or more rarely by direct injection into plants

The concept of systemic plant protection is based on evidence that certain organic compounds are absorbed in minute quantities by crop plants and either serve as protective substance against infection or stimulate living host cells to produce compounds which resist the attack of pathogenic microorganism It is hoped that certain of these materials may prove effective against the attack of fungi bacteria and perhaps viruses which are difficult to control by conventional methods In fact there is encouraging evidence that it may be possible to control stem rust of wheat apple scab and bean blight with systemic compound

The more common crop protectant include inorganic and organic compound of sulfur copper chlorine mercury zinc nickel cobalt and the quinones and phenols (*see* PHENOL QUINONE) Those that appear to have systemic effect include salts of heavy metal such as iron mercury zinc and lead the sulfamate salicylic and picric acid dithiocarbamates certain fumigant such as methyl bromide and the herbicide 2 4 D and 2 4 5 T (*see* FUMIGANT HERBICIDE) A number of antibiotic substances extracted from microorganism have been shown to act as systemic protectant (*see* ANTIBIOTIC) Example are Actidione streptomycin and antimycin from *Streptomyces* species fungocin from a species of *Bacillus* and viridin from the fungus *Trichoderma* (Fig 2)

Weed control Because weeds are plant pests to the extent that they compete with crop plant and serve as reservoirs of plant pathogens and host of insect vectors (carriers) the plant pathologist includes weed control in the general area of plant protection For the chemical control of weed complex compounds known in the trade by such names as 2 4-D 2 4 5 T TCA IPC and 2 4-DB are used Some herbicides are toxic to the weed treated whereas the selective herbicides are principally growth promoting substances which over stimulate living tissues and ultimately cause their death [J C H]

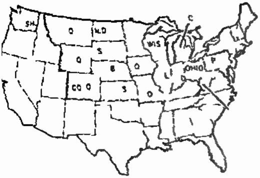
Disease resistance Growing resistant varieties of crop plants is the best and most economical way of combating plant diseases No capital labor or time need be expended in applying protective fungicides if the crop varieties grown can resist the ravages of disease

Varieties that have no natural resistance to a pathogen often escape disease infection and damage merely because they mature early or because of their growth habit For example certain wheat usually escape rust because they ripen early bush type beans are less frequently attacked by the white mold *Sclerotinia* than are the vine type

Better understanding of the specificity of resistance comes as more is learned about parasitism and disease processes physical factors and mechanisms chemical components and combinations and enzyme systems and energy exchange Even without full understanding much has been done in utilizing and combining the kinds of resistance studying the inheritance of resistance investigating its variability and practical testing for its dependability

Heritable resistance A true natural resistance however is a heritable character sometimes governed by a single gene sometimes by many genes Resistance is based on structure protoplasmic properties metabolic activities and physiological functioning of a variety it may vary qualitatively with external environmental factors Usually it is effective against a specific pathogen but not against all pathogens Immunity connoting com

Fig 2 Control of downy mildew of lima beans a t ptomyc s lfat comp d Ag t [illegible] ( ) Un t t d 100 [illegible] f ct (b) Sprayed with 100 ppm streptomycin [illegible] t co t l W J Z m y SDA



ig 4 M th 513 500 000 r t s pt bl b ry b h h b e d t y d 153 000 d ff t f d ba p op rt th 19 b b ry d t t t (USDA)

gat o t prot ct its ag cultu al re ou and nd try f m the d t uct e ff ts f ot pla t d a e d p ts

Th tra t t f pl nt a d plant p t wa l m tt of pr ate ern w th the r lt th t m y pla t p th g n b cam w dely d t ib d by nt tion l t el o th gh nr t t d t d h nn l Th d ng rs f th tua t b m d amat c lly appa e t f ll w g the a d ntal ur p tat n f the he t ut bl ght f n g nto the Un ted St te f m A between 1900 d 1905 d the ult mat d tructi f the Ame h tn t f r t

A a eq ne f th d th b tte l th U t d St t Go r m nt 1912 pa ed th t n l Pla t Qu t A t T day e t ll ll tu h ct d p t t q a t g l tu Q r r e l w th rt e Fede al tat ff l t nt r ept d nsp t h pm nt of pl t m t r l a d t l as f m g te fis th h pm nt n a co d e w th l gal p Q r t n pect r t t ed at p rt f ntry b d st t n d at e g d d s tr but g p t fo f ht nd m l

V l f qua t Th lue of qu t s t l g b n d puted Ant go t el m that ma ble t p ev nt th mo m t f m op e p th g th t ma y q a ti r tifi ally nd d th t m as s q a *ant n* b u ed m ct te t t f f e t d nd ha e a ed n y omi l S pp t t t th t eu th gh n t 100 ff t e q r nti e d p ve t th nt o d t on of m ny pe t a d di a s nd t d the m ment of othe g t t t me t m bat th m b f r th y be m well stabl h d th t q a ti u lly th g ultu l du try m ll n of d ll a d th t th c n m g m y t m g te th n ny p ble b n l r lt ng f m th ppl t f q r t em

Imp em t in th p t f q r t i g m y pr d a th t ll q t e will be establ h d n nd b l l b fo m xim m ff t th t th y e b l ft d with q l f cilty when it bec mes cle r that they are no l nger nec ry and that in far a po ible new quar ant ne laws w ld be preceded by i t rnati nal onsultatio in a att mpt t ol tain m t al agre me t nd t r minim m d rupti n of the i te nati nal exchange of commodit e

Int rn tion l dis ase pr tecti Joi t ff rt are m de l y nat n t protect their ag lt ral r ou ce and indu tries without impa rment f change f c mm d ti Ideally a ailal le knowl edg o pla t pe and path g t utiliz d t devi meth d t l mit thei geographic pre d and t pre e t the utbreak f epidemic Change in c pp ng p tte in trade agr em nt nd in the di tributi n of pe t a d patl g n ne e tate a e ti uing program c n ting f (1) a nt l plant di a e surveys by the ev ral nati ns with free ex h nge f ults (2) the rig r u pra tic f local an tati and plant pr tecti n (3) th prompt di tril ti n of res ta t ari ti f r p pla ts (4) the change f inf rmati in im pro ed c ntr l m a ures and (5) int rn t nal c n ultatio with re pect t the estal l hme t a d *enf rc me t of q arant ne*

I t rn t on l pl t pr tect n ca le ucces ful nly when eg latory acti t e ar f tifed l y ci nti t n e t gat ng the eti l gy f pl nt d a e l fe cycle f path gen ho t pa a t relati hip d ch mic l nd ther c ntr l mea u e F ha g t by ci t fic pe nnel f rth r tre gl en der t nd ng d lead t log l and m ll agree m nt Amo g inter ati nal organ zat ns t e *i pl t p t t o a* the Food and Agr cult r Org n zati of the Un ted Nat s, and th Inter nat nal Comm s on o Pl nt Di se Lo es

[J C H]

B bl og aphy E C. St kma a d J G Harrar *P i cipl f Pl t P th logy* 1957 A St ff ud (ed) *Pl nt D s s* USDA Yearbook Ag 1953 J C W lker *Pl t P thology* 2d ed 1957

Plant evolution

That pl e of ev l ti deal ng w th the gin and d l pme t f the pl t k gd m Th articl d us luti nary pr ce e dy am c a d volut o a y h st ry phyl ge y

Evolutionary processes The proce es of pla t l tio —m tati g etic re mbinatio at ral el t n a d r p d cti e i lat on— r the am a ll f m of l fe b t n fo nd diff n b twe an mal nd pl nt in th m d f l fe b i t u t e a d ind d al d l pme t b g bout c rr p ndi g m d f ti i the mode of a t *n and lat* mj o t n e of th fou p o s S ne pl nts th r m n fa t f od by ph t nth s or a phyte or p a sit s ab rb it ft r ett g d g t e nzymes int th *d ng m d m th y l k i t g t d* y t m fo nge t on d g t d x t B ng ti lly n m t le th y l l k th st mu lu e y tems wh h n imal h w the high t typ f nt gr t n B c u th y ab orb ath th nge t pl equ n in a f e

Wild and cultivated plants Wild plant species that have undergone natural selection frequently have more disease resistance than do cultivated plants especially if there has been long association of the plants with the disease organisms *Solanum demissum* a wild potato with small tubers is more resistant to late blight disease than are the cultivated varieties of *S tuberosum* and many other species of *Solanum* growing throughout the highlands of South America are being investigated as sources of resistance to late blight or some other diseases The small fruited wild tomato *Lycopersicon pimpinellifolium* has more resistance to a number of diseases such as bacterial wilt fusarium wilt verticillium wilt bacterial canker gray leaf spot leaf mold and the spotted wilt viruses than has the cultivated tomato *L esculentum* Sometimes by selection and by hybridization the disease resistance of a wild plant can be incorporated into varieties suitable for cultivation

Cultivated crops sometimes are heterogeneous populations from which resistant individuals can be selected and propagated The simple selection of survivors in a plant population subjected to repeated severe attacks of such soil infesting pathogens as *Fusarium* or *Verticillium* has been one means of obtaining varieties of cabbage cotton flax melon and tomato which are resistant to various wilt diseases Growing flax year after year in a soil plot infested with all available and known strains of the fusarial flax wilt fungus propagating from the survivors and again growing the progeny in the infested soil eliminates the wilt susceptible portions of the population By persistent selection of this kind flax wilt has been controlled in the United States for about 50 years

By hybridization many resistant varieties have been produced in wheat oat barley cotton flax potato tomato bean cabbage melon cucumber sugar cane sugar beet tobacco and various other crops Simple and complex crosses polycr e species crosses and backcrosses have been made and isogenic lines have been produced in some instances If genetic characters for disease resistance are available they can often be combined with many other desirable characters in spite of difficulties encountered because of lack of synchronized flowering in the material pollen sterility and linkages The search for resistant materials may cover wide territory For example sugar canes from Java and India supplied the most resistance that was needed for cane in the United States and wheats from Australia and Kenya furnished resistance to race 15B of stem rust for many new wheat hybrids in the United States Canada and Mexico New sources of resistance are continually being sought in the varieties and genic lines assembled in world collections of various crop plant

In times past when some diseases has threatened destruction of certain crops and discontinuance of their cultivation resistant varieties have made possible their continued production Today the aim is greater foresight by planning adequate testing of resistant varieties by having various kinds of resistance at hand and available and by facilitating rapid replacements or recombination of crop material [H B L]

Eradication campaigns These are designed either to eliminate recently introduced pathogens completely or to protect economic plants by destroying alternate or weed hosts Success in eliminating pathogens depends on early detection of the pathogen and on the efficiency of eradication measures

Attempts made in the United States to eradicate chestnut blight and the Dutch elm disease were unsuccessful The citrus canker disease however was eliminated from Florida by burning infected trees Flag smut of wheat which was introduced locally into Mexico was also successfully burned out Similarly persistent eradication of infected plants has helped restrict many diseases See FRUIT (TREE) DISEASES

Certain rusts can be controlled wholly or partly by eradicating alternate hosts For example the destruction of red cedars near apple orchards protects apples against the *Gymnosporangium* rust because this rust cannot maintain itself on either host alone To help control stem rust of wheat and other small grains the growing of barberries *Berberis* spp has been prohibited by law in countries Denmark began a successful campaign against barberries in 1904 and in the United States about 500 000 000 barberries have been destroyed since 1918 with substantial reduction of the stem rust menace (Fig 3 and 4) Likewise in the United States white pines and other susceptible species are partly protected from blister rust by eradicating nearby currants and gooseberries *Ribes* spp

Like legal public health measures for human beings and for domestic animals those for plants are essential in keeping many diseases in check [E C S]

Quarantines Plant disease quarantines are legal measures taken by Federal or state government to prevent the introduction of foreign plant diseases or pests into an area Quarantines are based on the philosophy that government has the right and ob

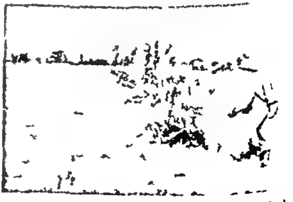
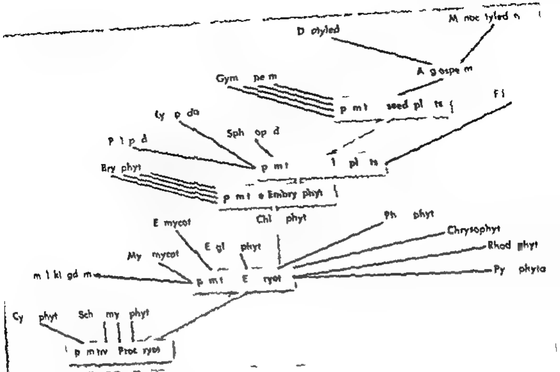


Fig 3 H mo typ ch mic l p ysa e u d fo k g u t s c pt bl bo be ry pla t Thi proc s much fa te a d l c tly tha m o s lt (USDA



Phyl g t d g m f th pl t k gdom

te t a d urn h th zygt nd y g mbr B t f e g n t n f th l f y le fr m d p d n wat f e l d l pm t ts t lut wa th m t mp t t gl t p t k by high pl nt g ing th l d It m d th t th a l e t Emb y phyta w d ff re t f m both f the r mod n d d ts the Bry phyta a d th T a heoph t p rtly b th h gr t m ph l g cal g ps b t th mod n gr p a w ll t tween th m and l g Chl phyta d p rtl l e f recently d d p b d nt t t f m fdl d ly P leo ge nd wh h pp tly b l nged t l d pla t Th v t fy t th iste f a e t e e ly l d ff a wh h ha l ft f w n f l tema The bulk f ent de f o th h m l g th r f th f th ltern t l g t c d g t h h thes a l t Emb ophyt l k m y Chlo- oph t p e f tw m phol lly m l g n t n F m th m e l t proc d d o d e t t w d th Bry phyta th h ghly d r t t d gam t phyt d edu d pa st phyt

I th p t d t th e ev l ed th T heophyt w th d ed b t fr l ing g m to- phyte a d th l ged p ophyt e g w ll-d f nt t d a l y t ms Th e nt t t d w l l of ad m t be a e th t f s pp rt a d d p rm tted th m t tt n l ge z a l d pl nt a d t d m n t th n m t D g th l te D d th tly Ca bo fe p iod th ga e n t many ad pt ly d t g l wh h m lud d th f t t Alth gh th l e t d m t T ophyt we po b a g b t g r lat d to th t n l h m (Ly p da) a d ho et l

(Sphe p da) e d b ar ng pl nt al eady x ted m ll umb r in th Dev n an p iod The f r al l ga th r ol t n at th t time nd e e th n h e been al undant t e n n hab tat

The l t eed pl ts and the d d nt c titute the f th d h gh t l vel f ad m t h e d by the pla t kingd m in g er l d d pt e ha e te t c They l d f ghly ff emt t tu s fo pr t t g the d el p g ga m t plyt a d n h ng it f m th m t al p rophyte f c f t l zat n f ll wi g t n pot f el t ely drought and t mperat resi t nt male g m t phyte (polle g a) and f p t ng d n i h ng the embry by th matern l p rophyte D ring th m t t equ bl f m te f the Carb n fe o p r d po l a ng nd d bear pl t w almo t qu lly f u d nt b t th d t the Perm an p od f old a d d lim te e the m r re ta t ed pla ts t em do sad antage They vol d al ng l l d n t t xt t g up to th m d e n d f gym p ms (Cy adal G nk g le G t l s Co f al) and t the a g o- p m o f w r g pl nts

The origi f ng p rms s u k wn The r fi t d ubted f s l are f om ly C ta ou t t 120 000 000 y a old Afte th tim they b am d ngly b nda t Old f agm ta ma s mo tly f w d a d p lle but l di g f w l ha d t f d s g p m by t s pl oh t n ts The l t a e f m the T a p rod d gg t that th g o- p ms m y be l 000 000–200 000 000 ye r ld d th t th u q t ned f l d n p t only th l tt t o-th d f th e l l o y D ri g the fir t 60 000 000–80 000 000

ternal urface area as their total volume in rea e wherea animals function be t if their b dy i compact and their increa e in volume is accompanied by a corre ponding increa e in surface area of internal organs Hence animal require a carefully integrated and centralized circulatory sy tem while plants need only a relatively loo ely organized decentralized sy tem of ti sue for conducting food and water

The compact body of animals requires an integrated pattern of development known as the clo ed sy tem of growth in which all ti sues and organs pass almo t imultaneously through tages of embryonal primordia youth maturity and old age The le s integrated organization of plant is produced by the open sy tem of growth in which the lea branche and flower are produced erially by specialized embryonic tissues or meristems so that embryonic youthful mature and ene cent stages may exi t simultaneously in different organs of the ame individual and the ame type of organ may be produced repeatedly over an indefinite period of time The developmental cycle of any particular organ in plants is shorter le s complex and le well integrated with other organs than in animal Con equently plant organs can be m dified much more profoundly by both environmental and genetic effe t than an animal tructure without producing inviability

Becau e of their general lack of motility plants have e ol ed pecial device for the di emination of propagule uch a pore and eed (s e POPULATION DISPER AL) In addition the flowering plant have evolved elaborate tructure which promote cros pollination thr ugh the aid of animal Together with the tructures which protect the pore and eed the progre si e elaboration of the method of cro pollinati n and d sper al of pore and eed form tl e principal thread around which the e olution of land plant i centered A econdary thread i formed by tl e a cular y tem which erves for conduction and support On the other hand the m dification of the out ard form of lea e and tem a well as of the inner phy l gical c ndition of tl eir cell which adapt plant to different hab tat and modes of life are of uch a ge eral nature that they are repeated in an almo t parallel fa l i n many times in unrelated group of plant They are con equently much le relial le as gnp t for the pathway of evolution than are orre pondi g maintenance tructure in animal

In addition the di eciou onditi n (tl at is indi idual di tinct a t ex—male r female) is far le wide pread in plant tl an in animal In ome plant uch a m e m n eci i typ (ha ing indi iduals l otl male and female) h been derived econdarily fr m dioe iou an t r

All of the al e m ntioned chara teri ti f plant l ave facil tated ev l uti n thro igl rec ml i nation of genetic characteri tic d ri ed fr m different adapti e y tem H l ri lizati n betw ul pecie and pecie i parti ularly c mm n i plant and the hyl rid deri ati e are often ig r ou and well adapted to new habitat They can l come tabilized in three different way by segregation of relatively homozy ou intermed type by introgre ion and by polyploidy The ma jority of species of hi her plant have prob evolved at least in part by one of the e processes

Evolutionary history The evoluti nary histo of the plant kingdom is outlined in the diagram (ee illu tration) Five level of advancement are recognized each ba ed upon an adaptive tem f fering new opportunities for adapti e radiati n Each level was first reached by a group ith generalized or primiti e characteri tic Thr adaptive radiation thi generalized rou gave rise in each case to a number of evolutionary lines or phyla the modern repre entative of which are very different from each other

The lowe t tage i the Procaryota or organ with a primitive type of nucleu lacking a clearl defined meml rane their gene are organized in aggregate le harply defined and les highl integrated than the chromo ome of hi her or isms their nuclear divi i n i le complex th typical mito is Sexual reproduction when pres involves a minimum of morphologically pecial tructure Differentiation i confined to the f rma tion of re ting cell or spore The primiti e Procaryota gave ri e to the Cyanophyta or blue-green algae and to variou lines of the Schizomycoph or bacteria (*see* SCHIZOMYCETES) Fo il tl green algae have been found in rock 1 000 000 00 years old

The primitive Eucaryota or organi m ith well defined nuclear meml rane chrom omes an mitotic cell divi ion were unicellular Their m ern counterparts are flagellate organi m h ha cla ified either as algae or as protoz a They ga ri e to eight different phyla of plant m t of the primarily aquatic which differ from each oth hiefly in their method of ynthe i or al orpt of f d The aut trophic phyla which collecti e are termed algae have de elo ed different pig p gment a ociated ith their chl roph ll The pigment enable them to al orb and u e for ph synthesi light of wavelengths characteri ti each phylum The heter trophic phyla wh h apr phytic or para itic are the M x m cota tl e Eumyc ta fungi Certain Phaeoph ta l rown alg e and the mo t advanced ba idi ete or mu hro m am ng the fungi l a e well differentiat d ti sue though the e are elal orate tl an are tho e of mo t Eml ry pl ta T mo t mmom l fe cycle in primiti e Eucar i tl e hapl id type in whicl mei i immediat f llow f rtilizati n and zyg te f rmat n Str dipl id life cycles are l e t known in the d at (Cl ry ophyta) and tl e Fucale (Pl aeoph C rtain Rl d ph yta Pl aeophyta an l Chl r ph po an alt rn tion of tw m rpl l gi a imil r gen rati n a hapl id gametoph te an dipl i l phyt

Th next tag of d ncement reacl ed b tain l ri ati e f tl Chl l yta in l rati n f tl ar l g t i

t t gether The former s bett r f r h gh vol w k the l tt r f h gh ı ty f w k

a s mbly the ch ı e betwe n mo ng th jo m ponent pr gres v ly t po nt whe e part r a mbl d ı ıt—lı pr d ction—fi ı g the l ation f the m ı r c mpo t a d ng g othe parts to ıt H r again olume and ty e nt ally det rmine the ch ı e

In plant transportation M t r als handl ng a d t layout go hand n h nd One ca eldom plan h nge o e w th ut affe t ng the othe

M te als handl ng s a u ersal production blem T form o d t o or a emble the ma ıal they mu t b m d t and f om the po nt op atı n

Pla ng ff ct mate ıals handl g n ol es ıe elect n of a b s h ndl ng y tem I dı du l andl ng equipment nd nt ers a e then fitted t th syst m The part c lar eq pment m y e h d tr cks erhead ra e o conveyo s An t grated m te ıals-h ndl ng ope ation dep d on h t ı ers and tta hm nt fo the handling q pme t (clamp h k b a k ts and the l ke) g pl nn d f r nterchang able

Altho gh ımp eme t qu pment are co t ntl be ng d pted th ba ı handlı g sy t m of a c mp ny ho ld rem n el t ely table Ind s tr es w th high ı ıt l n estme t ın fa lıtı and w th elat ly fi ed product pr e s s nd equ p m t e tabl h a sy tem f h ndl ng o nd wh ch the pl nt s ro t ted Fa t r w th freq ent mod l ha mat fl x ble a d c n tantly x mı ı g th h ndl ng m thod fo mp eme t (e MATERIALS HANDL NG)

Production lines A p do t l ne s n a r ng m nt f w k pl ce n th qu nc f p at n I t ptım m form prodo t o l n m es th m t al th ugh a e s f bala ed pe atı a m thly a d t uously n form at f fl w th a h p r t on b g l ted m m d at ly dı c nt to th nes wh h p ecede nd f ll w t

Th b a g th t m f m ng l e pro-d tı n clud edu ed m t r al handl e f p od t t l and op rv on ımp v d ka m th d f t g ke s e-du ed n e t ry ı p e nd sh rt p du t t me O th th h nd p d ct n l nes q re ub ta t al ol me f blı t nd d z d —o at l t s m lar—p d ct A ult th m k t g nd pr d t d gn f a mp y g e tly ın fl th b l ty nd t r f ıts p od ct n l Oth l m tatı n n l de d l y d e t b k d wn t pro ıll wo k d e t nb l n ed p t t mes d g ate tm t m h b c u t t l zat eld m gr at n a l y ut by p

f me c th phy l ab l ty a d ec om p a t ality t m th p od ct f om e op r t n t the t l m t th ppl t n f prod t l

F the r aı d ct n lines fo a sembly to t up th th fo form g f b Th e m ny a ı t s f th l n n

cept with the ultım te aeld m pro ıng practical Flex l lıty of the line to accomm date changıng pr duct materials ı ro es e chedule and p r s nnel ıs far too ımpo tant t pe mıt very many comp nıes to go all tl way to the c mpletely syn cl ronized and automatic prodı ctı n line

A pr duct n line ı scheduled and perated a a unıt n t as ndı ıdual peratı ns Its wo ker g n erally need b trained to do l ut a s ngle operatı n The e two f cts can cau consid ra le change ın the typ f employee and the proced res f oper at g n rganızatı n when ıt co verts ıt pera t o s t production l nes

Maintenance V t l to any low-c t ındu trial p-er t on ı good maıntenance of ıts fac lıties Par t c larly s th s s as ı du try continues to sul t tute power ı eratı ns for hand l bor The l reak d wn of but o e k y operation can metime cau th shutdown f an entire plant becau e of ıts syn chr nızatı n with sul eq ent peratı n

Pre entı e maintenance such a clean ng adju t ı g e h ngıng and l b ıcating on a programmed ba ıs el m nates or b ta tially reduces sh tdown du t ma hine fa lure This ıs pe hap the m t mp rtant functı n f a pla t s maintenance gro p Oth r fu ct o s may ınclude ın pect on repaı o e ha l recon tructo alvage wa te dı po al pla t prot ct n and t r k ep ng

So d er e are th p oblem f ma nt nance that o e p rson mu t be a ıg ed ıt esp n ıbility M t n ce sh uld b planned cheduled and ef fic ntly e tted but ıts c ts mu t be subj ct ın p rt t the va lab lıty f f nd Its acc mplı h m nt h ld m asured l y perf rm nce rather tha th amount pent for f qu ntly n t enough m ey ıs spent ma nten nc of machı ery equıpm nt and pl nt for effi ent o r all op ra t

Safety and fire prevention The o t t ı d stry a h ye r of ı t r upt ns du t ac ıdents and fires s ub t ntı l pu ely d Ir m n n eco mıc on de ation

I ur nce on w y of m nım z ng l fi e ıt g h a d fi st aid stat n are other w H we el m nat on f the c es a d opp r t n t fo a dent to occ ı a m r d rect a drew d g appr h

Safety ules—e tabl h d f r the specifi plant ı l d and o tently nfo ced— e well w th the fi rt Detailed l s f spec fic equ pment lo-ated wh they ar read l efo e th ma h s u d e a ther p caut

F effe tı fi e c t l ry ı la t n d a fi e d tect n a d larm v tem nkl maıns hy d a t nd t ngu h Spe ıfi equ pment d p nd n the nat e of the nd try p odu t p nd pla t S FACTORY INDUSTRIAL EN GINEERING PRODUCTION METHODS [R M]

Plant fermentation

A f m f pla t metab l sm wl ıch ca bohyd tes r p rt lly d g ded with ut the c n umptı n f m l ula o ygen Appr x m tely 85% of the p t ntı l ne gy of th c rb hydrat s ıs r le d

years of their existence angiosperms may have grown on mountain tops or hill slopes where preservation as fossils is difficult or impossible *See* PALEOBOTANY

The ancestors of the angiosperms may have belonged to the extinct pteridosperms or seed ferns Anatomical evidence suggests that the most primitive angiosperms were trees or shrubs but evidence from both fossil and the morphology of living forms indicates that herbs related to the waterlilies (Nymphaeaceae) and buttercups (Ranunculaceae Paeoniaceae *Kingdonia*) appeared very early in angiosperm evolution Dicotyledons are in many respects more primitive than monocotyledons but evidence such as the occurrence in Triassic strata of fossil leaves which may be palms indicates that monocotyledons diverged from the primitive angiosperm stock at the beginning of its evolution and evolved simultaneously with dicotyledons *See* BRYOPHYTA CHLOROPHYTA CYANOPHYTA EMBRYOPHYTA EVOLUTION ORGANIC GYMNOSPERMAE LIFE ORIGIN OF PLANT KINGDOM POLYPLOIDY PROTOZOA PTEROPSIDA SPECIATION THALLOPHYTA TRACHEOPHYTA [G L S]

Bibliography A J Eames *Morphology of Vascular Plants* 1936 G M Smith *Cryptogamic Botany* vols 1 and 2 1955 G L Stebbins *Variation and Evolution in Plants* 1950 A L Takhtajian *Origins of Angiospermous Plants* 1958

Plant facilities

The physical properties owned and used by industry constitute the plant facilities These include land and site improvements such as roads rail extensions parking lots and fencing buildings such as factory warehouse office areas other structures such as docks liquid storage tanks incinerators and gas generating systems and machinery and equipment used to produce or condition the products of the plant or to support the producing (or conditioning) processes

Location An industrial plant is often located merely by preference of one or a few owners of the business Large companies make a detailed study before deciding on locations for new plants The decision is based on many factors most of them are economic and relate to the costs of transportation (for incoming materials and outgoing product) of material of labor of taxes Many industries depend directly upon their source of raw materials and the market area for their product Other industries consider first the availability of attractive features like space freedom from adjacent dirt and fume trained labor supply water and utilities Another factor is community climate or the attitude of the people and their leaders

A thorough plant location study includes evaluating the availability suitability and long range cost of land site raw material power fuel water utilities market area transportation facilities labor supply community conditions taxes public relations value laws regulations and external hazard

Plant layout The layout of an industrial plant embraces the arrangements and orientation of the physical facilities including storage features and supporting services used by the company in the production of its products Planning a new or rearranged layout involves four basic phases

1 Determining the location of the area to be laid out is not necessarily a plant location problem More often it is one of analyzing whether the new department or expansion should go on the north side on the third floor or in a separate building

2 Establishing the general over all layout involves relating the major activities or departments to each other and allocating the necessary area to each At this phase major features of the producing machinery material handling equipment utilities and the building itself should be incorporated

3 Planning the detailed layout includes the locating and orienting of each machine working operator material in process container and supporting service

4 Installing the layout plan involves coaching or training personnel in the procedures and methods on which the proper functioning of the layout has been planned and moving placing and hooking up the machinery and equipment

These four phases fall in chronological sequence but always overlap each other Also these four phases make logical check points or organizational divisions for the supervisor of plant layout work

Effective layouts are based on flow of material to allow sequential movement of the material being produced or conditioned As a result determining the flow is the heart of most layout projects As the number and diversity of parts or products increases the complexity of flow analysis grows and the methods of analysis change

Diagraming the flow and then assigning to the diagram (or diagrams) the space required by the activities are steps that follow determining the flow These steps lead to a physical arrangement of space Integration of supporting services with the flow pattern and modification of the arrangement in accordance with practical limitations of the handling and storage facilities machine utilization building features flexibility opportunity for expansion and personnel needs and conveniences lead to the desired layout Alternative plans are usually developed By comparative evaluation the most effective is selected

Layouts are most readily visualized by making a three dimensional model of the proposed plan But this is not always necessary Two-dimensional scale template representing the space—and the individual pieces of machinery and equipment in detail layout —are always practical With modern plastic material many different layout plans can be made and reproduced with a minimum of draftsman hand drawing time

Classical plant layouts center about either the product or process wh n f rming or treating m ter l i invol ed Layout by product arrange all facilities required f duct t g th o it l p o l cat

lte call d zyma e Nearly all the enzymes and nzym r q d f alc holi ferm ntat n h e n w lee d nt fied fr m extr cts f h gh r pla ts (pe b an mu g bean and whe t mbry s) F m nt to m y be ar d o t in ll f ee and c n e t at d pl nt e tr ct pa t la ly f the t a t a e f rt fi d with gl c m rg n c ph phate a d the n ym s e e rl xyla e d pl ph pyr d e l t de and aden netripl phate S e COENZY IE ENZYME

Role of fermentation The pl y l gi al le of f m tation high r pla t a till u e rta n E e pean d e Am c n pl nt phy l g t h ll d fer tat n i high r pla t an ol p t t mof cula p ati n How r th e t ms a e d p[e]a i g fr m e in N rth Ame c Re t o m lar t fe me tati n ar impo t nt n tl n t l st ge f pla t e pirati (s PLA RESP R TION) F rm ntat n may up- p y a l bl (rm f e g d r ng g rmi tion f seed o n pla t part filt t d w ll wat r W th th xc pt o of few h gl r pl nts f ampl e (O y r m) all g owth a at l w xyg p s, b t fe m ntat may t ll s pply n rgy f ma t nan f t ady t te a d y th e tial fo rmal An r l b teri d ye t m y g w n th ab n f S FERM E TATION PLANT IETA OLI I YEAST [D R C]

B bl g phy J B n *Pl nt B h mi t y* 19 0 W O J m *Pl t R sp ti n* 19 3 F C. St w rd (d) *Pl t Phys l gy* ol l a d 2 19 9

Plant geography

Th t m j r bd i n of b ta o d w th ll pects of th p t l d tribut n f pla t Th c f k w phyt g gr phy pl t h l gy r g ph l l t y By t dt t l a l e mea j ts f the d t b t f pl nt t me h t r al pla t g g aphy p l ecol y and p leobotany In ts h to al de- l pm t pl nt g g aphy ha l t m t ly c n t d th the t f l t l ey nd g t ft t y t n t tly g e t d f m l g) Fr m d d q lly l g l w p t pl t g g phy m j bd o f th f ge g ph lth gh by t m f w g g ph d l ma nly w th pla ts Th w d g bot y d abl t l g lly nf t g t ri b f um nd ntr d t y e g

Th f n t f pl t g g ph t e d th l t d p r l fa r f pl t d t bit nd l t d t d d te p et th e f t Wh p bl th t d n l d th p ed t d t l f d t h t al ph n m p tall s th lat t pl nt p t a d t the t du t n d pr d f d t hl pe d g tat n typ S h p t l p t r p t nt to th fi ld f f t agr lt r g nd p tu e m ag m nt w ldlif h b t t m g m nt h ti h a d il d w t n r t Pl t g aphy t lly n t a p m ntal

and m g ne al d es n t s I e lat rat ry proce d res an f techn l g al q i j ment

Flora and vegetation Tl re are tw maj r ul dur t f plant geogr phy parall l ng n l gical b akd wn f l tany ii lf Fl r ti pl nt geogra phy ml ra e the pat al di tribut n of the fl r wh l eg tati nal pl nt geography t the pati l d t ibut n of the eg t ti n A cle r und r tand ing f the two t rm i e t al

Flo a t a t nt fic term with mm n age The flora f an rea r p d of time s the to- tal ty f all the p ies with in th t geograph al n t ind pendent of th r r l ti e f d n es and the r relatio h ps to ea h the Th t l n al term populat n n thi c n t refer ll c t ly t all th i d d al f any j ci within a l cal ty

V g tat o i a t m l p p lar or g n and refer t the ma s of pl nt life that f m the natural m natural l nd c p Th eget ti f a r gi n is th t re t y or carp t f pla t l f de el p d l v d ffer nt l and *a ying omb n ti n a d growth* f the um o lem nts of the l al fl ra T ch n cally it rga zed a d i t gr ted wh le t a higher le el f nteg ati n th n th p rate p ci mp ed of tho e spec es and the r popula t o Som t mes get t e y we kly int gr ted a th p ee pla t f an al and ed fi ld Som t mes t i h ghly i t g at d n the trop al a n f r t Veget ti n em rgent pr p er ties n t e a ly f n l th p ect th m el es I r fe d t by nb l g t a a *typ of o* g n m a d ff r t d m s lu term th n th g n m f b l g t

Floristic plant geography Th b mpon nts f ny fl a e the k nd f pla t c mpo ng t mm nly r f rred t as pe ies The pecies ca be gr uped to ar us k nd f fl r l elem t wh h a e n *t mutually ex l* e F r e ampl a g et eleme t h s a mmon evol t o ry ig n m g ati n element ha a c mm n ute of ntry nto the t sto y a h st ical elem t s di t ct t rm f me p t e nt a d an l gical le- m nt t lated t a en mental p f e Al ns e e p d v ry w de p e d p te a e g ven pec al t e im nt An e dem c p e r tr t d t a r a s lly mall a d of m p l nt t S POPUL T ON DIS ERSAL

Th ide f a a t fund m ntal t the r n e nd t elf tl ject f a re al ed t n alled g aphy A r tl t reg n f d st but on u e e f any p e leme t en ent e fl The lo l di t b ti n w thi th r a wh l a th t f wamp h ub s th t po phy f th t a ea Ar a f ter t s g d t th g n r l nd hap tl e na t r f th m *g n* h th they t d sj t and m th t elat n h p t th a a G o p f a a e n i e t i p l e ntric whe th or t t to ne ral g gr ph ally d t t t A e l cl el relat d pl ts th t mutu lly l t e d t b a t u A l t a t e ry g l m l nd m te oc u n e

the remainder of the energy is transferred to the organic compound re ulting from the fermenta tion Of the energy relea ed approximately 44% in forms available for cellular work and the re mainder is degraded to heat *See* CARBOHYDRATE METABOLISM

Products of fermentation The products of fer mentation vary with the organi m but in higher plants the usual products are ethyl alcohol and carbon dioxide In ome ca es mall amounts of lactic acid are produced and other organic com pounds of uncertain structure may be formed for example in potato tubers

Certain incomplete oxidation such as the oxida tion of ethyl alcohol to acetic acid by *Acetobacter pasteurianus* or of sucrose to citric acid by *Aspergillus niger* are called fermentations in industry However becau e these proce es are strictly de pendent upon molecular oxygen they are not fer mentations *See* INDUSTRIAL MICROBIOLOGY

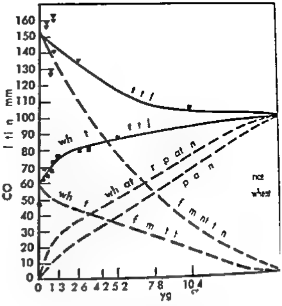
Fermentative capacity is wide pread and i known in many lower plants including yeast cer tain fungi and algae and in mo t higher plants and animals In higher plants fermentation often oc curs hi_h velocity in embryonic tructures such as eeds eedlings young roots and hoots The velocity often decrea es during development and may cea e entirely in mature stems and leaves of certain plants The occurrence and rate of fermen tation are illu trated in the table

Effect of oxygen on fermentation The partial pressure of oxygen has a marked effect on fermenta tion Except in a few obligate anaerobic bacteria fermentation ceases when the oxygen pre su e in the cells exceeds values of 3–10 mm Hg The sup pre sion of fermentation by oxygen is known as the Pa teur effect The external pre sure of oxygen tl at ju t inhibits ferment tion known as the e tinc tion point is a illu trated This pressu e is con siderably higher than the internal pre ure and i often 20–40 mm Hg in range When rice or other eeds germinate under water the ti s es may lack oxygen and fermentation re ults If the intercel lular space become injected ith water the cells often l ecome deficient in oxygen with a resulting fermentation This is due to the f ct that oxygen diffu es 300 000 times as rapidly in air as in water or tis ue

Forms of fermentation Two forms of fermenta tion are illu trated in Eqs (1) and (2) and mixed

Occ ce and rate f rm nt t on i ba ley ice and ca rot

Pl t	R t µl CO / (g w t wt)(h)	Alcoh l CO t
B l y		
C so ked 1 h	83	
S edl gs 6 h ol l	31	
Seedl gs 4 d y old		
I N 3 l	5 1	0 33
In N 9 0 h	8	0 7
R		0 98
Seedl gs 4 l y 1l	1	
C rot		1 01
Root l	80	



The fl ce of O ten o the e ol to f CO by tact seedl ngs of wheat a d ce T t l CO respira t CO a d fe me tat on CO_2 e sh w (F D L Taylor Am J Bota y 29(9) 721–738 1942)

reactions of alc holic and lactic fermentati n ma occur Equation (3) hows that the lactic acid ma be neutralized by the buffers of the cell

$$C_6H_{12}O_6 \rightarrow 2CH_3CH_2OH + 2CO_2 \quad (1)$$

Glucose Ethyl alcohol

$$\Delta F = -51\ 4\ \text{kcal}$$

$$C_6H_{12}O_6 \rightarrow 2CH_3CHOHCOOH \quad (2)$$

Lact c acid

$$\Delta F = -45\ 8\ \text{kcal}$$

$$2CH_3CHOHCOOH + 2KHCO_3 \rightarrow 2CH_3CHOHCOOK + H_2CO_3 \quad (3)$$

$$\Delta F = -4\ 95\ \text{kcal}$$

In pecti n of Eq (1) shows that alcohol i more hi_hly reduced than sugar wherea the carbon dioxide is more highly oxidized Equation (2) ho that the methyl gro p of lactic acid i m re reduced and the carboxyl group i more oxidized than the su_ Therefore fe mentation ha been kno n a an intramolecular oxidation reduction Further Eq (1) shows that the rati of carb n dio ide t alcohol should be unity and although thi alue i often attained de iations from it are common Ex e ces of carbon di xide o er alcohol is common as a re ult of nonfermentati carb di de p odi ced from the decarbo ylation of organic ac d (keto acids) or of the liberation f carbon d oxide from l icarl onates by ac d of fermentation or a s re ult of mixed fermentation with other reduced compound in add tion to r in place of ethyl l hol

Materials used in fermentation Fermentat n may occur at the expense of tar h glycogen or a y of veral ugars It is an enzymatic proce depend ng upon a y many enzyme a d ever l enzyme Tl me

ft ll d zyma Ne ly ll the enzym s nd zym q ed f r al h he ferm ntati n l a e n w been id t fi d fr m e t a t of h her pl nts (pea h a s mu h and wheat emb y s) F rm t t ma b ed t in ell fr e a d r n e tr ted pla t e t a t p t c l rh af the t ts ar f rtifi d with gl o e in rganic pho- ph t nd th zym s c a l xyl diphos ph py id ne nucle t de nd d n net iph phate S COE ZY IE FNZYME

Role of fermentation Th phy olog al r le f f n tati n i h h r plant i t ll ne ta n p n d me Am i a pl nt ply olog t h ll d ferm ntat n hi h r pl ts a aer b t p t n r nt m i c l e t ati n H w r th e t ms a d sappe r ng f m N rth Ame a Rea t m la t ferm ntat n are imp rt t th t al tag f pl t e p r ti n (s PLANT RE PIRATION) F rm nt t m y t p ply a labl f ms of e gy d g g m n t o f seed r m pla t pa t filt ated with wat r W th th e pt of a f w h gh pl ts f x mpl r (O y ae t m) all gr wth cea e t l w oxyge pr res but fe m t ti n may t ll pply en rgy f ma t e of te dy tate nd sy th ent al f rs val A ol b t d ye t m y g w n th b e f ar S FERMI TATIC PL NT METABOLI I YEAST [D.R.C.]

Bibl g phy J B n *Pl t B h mi t y* 19 0 W O J mes *Pl t R p t n* 1953 F C St w d (d) *Pl t Phy logy* ls, l d 2, 1959

Plant geography

Th t m ubd n of b ta y ned w th ll p ct f the spat l d t l t f l t Th n al k ow a phyt g g phy phy t l logy ge g aph l b ta y By t ad t n t l n ol me t t the d t b t f pl nt n t m r h t r al pl nt geography le e l a d p leobot y l t h to al de l pm t pl t g g phy h b ntum tely n e t d w th th f of t e l gy a d g n t c It t y t t tly gr ted f m l gy F om d d q lly l g al pe t pl t ge ph m y ld f th n f g og phy lth gh by t m few ge g aph d al ma nl *w th pl t* Th w d g o- b ta u d bl t m l g lly f ng t m b u e f um o a d tr d t g

The f t f pl nt g g phy t d th h rv d emp l fa t of pl t d tr b t nd l t d t d nd i t p et th f t Wh p bl the tudy l d the p d t n d t l f d t l ut l pl n m p c lly thes l t t pl t p r t th t od to d pr ad f l bl p a d g t t n typ S h p t l ject e p t t t th fi ld f f est y *ont lt* g d pat m g m nt w ldl f hal t t m agem t h rt cult d l a l t n rvat Pl t ge- phy ENCEN se t p tal

a d in g neral do s not t l e lab r tory p o e dures nd te l l g cal t ipment

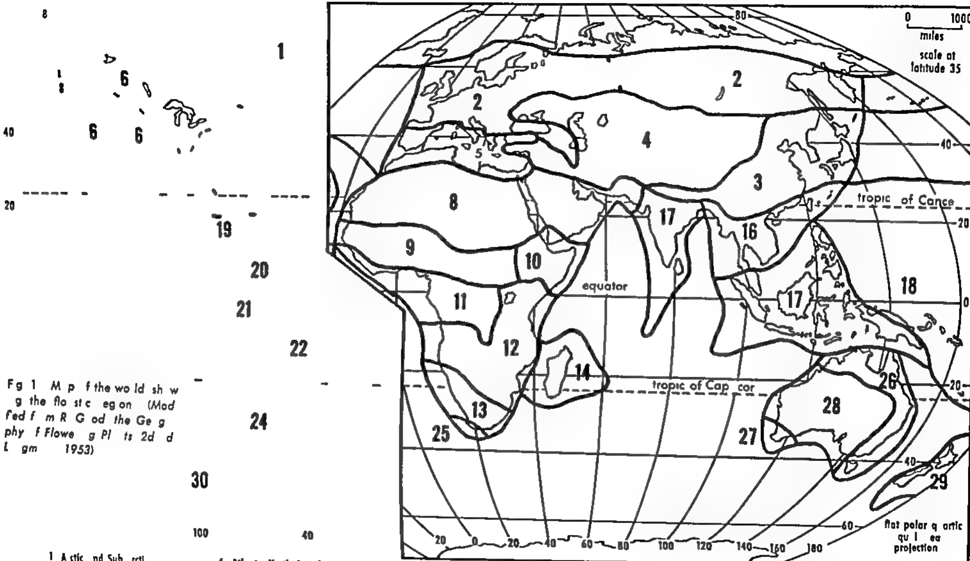
Flora and vegetation There are two maj r ul d f pla t geography p llel ng on l g cal l e kd wn of botany it elf Fl ri ti plant ge gra phy mbraces the spatial di tr but of the fl ra while egetat al pl nt geography s the patial di trib uti of the veg tat A clear under tand ing f the tw term i e ential

Fl ra t a e entific term with no c mmon u age The fl ra f a rea perio l of time i the to- tal ty of all tl pe t within tl it geog apl i al u it i d p dent f their relati e al nda c a d their relation h p t each ther Th te l ni al t rm pop l ti n in th s c nnect n ref s oll ti ly t ll th i di idu l f a y ne pecies within a l c lity

V g tat on t t rm f p pular or gin and ref r to the ma s of pl t lif that f rm th natural mi atur l land cape The *tat n of a r g* s th t pe try r arpet of pla t l f devel p l l y differ t al a d arying c mbin ti n nd g o ll f the mer us *eleme ts* of the l e l fl ra T ch i ally t an rgan zed and i teg ated wh le at higher le l of int g ti n tha the eparate pe ci s mp sed of th p s and their popul ti n Som t me getat n i very w akly inte grated s the p n er pla t f n ab d d f ld Somet me it i highly te ated in the tropical n f t V g t ti n *e e emerg nt p p r* t n t e r ly f d in th pec them l d r f rr d t by n nbiol gi t as type f r g n m d ff t and m e i l si t m than the o g n m f b l g t

Floristic plant geography Th ba c compo ents f a y flora e th kind of pl nts mpo g it omm nly fe r d t as pec The p cie be g uped nt a *u k ds* f fl l l ment whi h re t ri *tually* lu i F e mple a gen t element h a c mm n e olut onary ig a m grat elem t has omm n ute f nt y t th te rt y a h t r cal l m t i di t nct in t rm of m p t e t and n of g al ele me t l ted t n en m ntal pr f n e Al en ape a f ry w d p ad t c g v n p ci l t e tm t A nd m p e r e- t t d t lly m ll a d of me pe l nte t S POPULATION DISPERSAL

Th d a of a ea f ndamental t th c ce nd rs nts ll th bj ct f a spe i li ed e i on ll d g phy A th ntire reg n of d t b t cur en e f any p lem t eve n nt fl ra The l cal d t b t w th th a whole that f w mp hr b i th top g phy f th t a e A r of te t d to th g al e a d b p the n t f th *m g n wh ther* they ti s d i n t nd n th l ti l ip t oth G ups f a e n c t p ly t i wh the gr at nt e o eve l g g aph c lly d t n t t nt i A f l ely l t d pl nt th t a e m t ally lu i e a d t b vi o s A l ct o e rvi g f m n a l r d m t n o u nce



Fg 1 M p f the wo ld sh w g the flo st c eg on (Mod fed f m R G od the Ge g phy f Flowe g Pl ts 2d d L gm 1953)

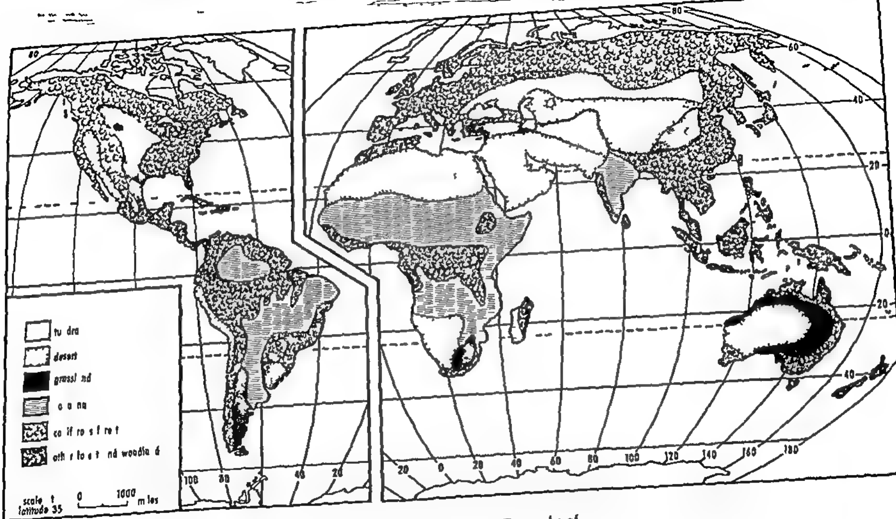
1 A ctic nd Sub rctl
2. E Sib ri
E p
b A l
3 St e pe es

6 Atl t c N rth Am ica
N rth rn
b S h rn
7 P lll N h Am t

11 W Af i R l f t
12 E Af St pp
13 S h Afri
M d

18 M l l d Ml l
19 C ibb
20 V l d G
l m

25 C p
26 N d E A t t
27 S W A li
c



Fg 2 M p f th w ld h w g th d trb to of phy g m veg tat typ (Aft B km J h m d f d f om R G d Th g phy of Flowe g Pl t 2d d L gm 1953)

On the basis of areas and their floristic relationships the surface of the earth is divided into floristic regions (Fig 1) each with a distinctive flora

The understanding and interpretation of floras and of their distribution have been predominantly in terms of their history and ecology Historical factors in addition to the evolution of the species themselves include consideration of theories of continental drift land bridges and orographic and climatic changes in geologic time that have affected migrations and perpetuation of floras Ecological factors more amenable to observation and thus unfortunately to post hoc reasoning include the contemporary roles played by precipitation humidity water levels temperature wind soil animals and man *See* PALEOBOTANY

Vegetational plant geography The basic components of the vegetation of any landscape are the plant communities The science of plant communities is known as plant ecology in the American sense also as plant sociology vegetation science and phytocoenology Many definitions of the plant community have been attempted but none has gained universal acceptance In part this problem is inherent in the nature of the community itself which is a natural phenomenon composed of elements the species which themselves usually maintain a high degree of independence Thus the community is often only a relative continuity in nature bounded by a relative discontinuity as judged by competent botanists *See* COMMUNITY

Vegetational plant geography has emphasized the mapping of so called vegetation regions and the interpretation of these in terms of environmental or ecological influences

There are many aspects of a mosaic of plant communities which could serve to identify a geographic unit of vegetation but that which has been predominant in the literature had its origin in folk knowledge It is the physiognomic distinction between grassland forest and desert with such variants as woodland (open forest) savanna (scattered trees in grassland) and scrubland (dominantly shrubs) Within forest the chief breakdown has been into coniferous evergreen forest broadleaved deciduous forest and broadleaved evergreen forests mostly tropical Furthermore the attempt is made to map original virgin vegetation as opposed to cover types obviously due to the influence of man (Fig 2) There is increasing dissatisfaction with this approach but no accepted alternatives have arisen Dissatisfaction arises from improved understanding of virgin vegetation frequently found to be influenced by ancient human populations Furthermore the segregation of coniferous from deciduous types is found to separate vegetations closely related in all other aspects such as yellow birch and hemlock in North America and to unite types otherwise unrelated like the pine stands which are found from the tropics to the Tundra edge In addition the distribution of grassland may allow the invasion of appearance of grassland may allow the invasion of apparently self perpetuating woody vegetation or recently self perpetuating woody vegetation or recer a in a manner that makes a physiognomic classification less fundamental Unlike floristic botany where evolution provides a single unifying principle for classification the nature of vegetation in its geographical distribution is such that many types of regions and many types of classifications may have equal significance in rationalizing the natural phenomena *See* VEGETATION ZONES

The interpretation of the distribution of vegetation has been overwhelmingly in terms of the existing average environment Catastrophic factors such as fires hurricanes droughts and other abnormal weather are receiving increasing attention There has been relatively little emphasis on differences due to the genetic nature of the species For example bristle cone pine trees have a life span of 4000 years and Australian eucalypts were absent from but by nature amenable to the environmentally similar but treeless California chaparral region From one viewpoint it is the varying genetic demands of the different species upon their environment which permits their segregation into communities The fact that arboreta and botanical gardens are so successful in growing many species outside their normal ranges is being recognized as a reflection of the more extreme environmentalist interpretation

The uniformitarian environmentalist interpretation of vegetation regions is the most completely documented Climate is considered of primary importance Numerous empirical formulas combining various features of temperature and moisture have been derived so as to correlate with the distribution of physiognomic vegetation type Soil is recognized as secondary in importance In addition biotic factors including both man and other animals have limiting effects Although analysis of the normal environment is essential to the full understanding of the distribution of vegetation types it is not likely that except for trigger factors direct and simple cause and effect relationships will be found between vegetation types and those elements of the total environment which man isolates and studies *See* ECOLOGY HUMAN ECOLOGY PHYSIOLOGICAL TERRESTRIAL ECOSYSTEM *see also* POSTGLACIAL VEGETATION AND CLIMATE [F F F]

Bibliography S A Cain *Foundations of Plant Geography* 1944 A Engler *Das Pflanzenreich* 1896 1900 A Engler *Die Vegetation der Erde* 1896 R Good *The Geography of Flowering Plants* 2d ed 1953 E V Wulff *An Introduction to Historical Plant Geography* 1943

Plant growth

An irreversible increase in cell number and cell size in plants In contrast growth in animals is almost wholly the result of increase in cell number Another important difference in growth between plants and animals is that animals are determinate in growth and reach a final size before they are mature and start to reproduce Plants have indeterminate growth and as long as they live continue to add new organs and tissues In animal growth of the different parts of the body is more or less simultaneous in plants growth is restricted to the gr

g nt or me t m (e MERISTEM APICAL MERISTEM LATERAL) The f e m an nimal t b dy cell has ab t the am age and the nd d al d as a unt but n a plant new cell p duc d all th tim and me p t ch as ie a d fl we may d e wh l th ma n b dy f th pl t p r t and o ti ue to gr w H w ver th ba c p oc f growth cell mult pl ca t n ry much the me in pla ts a d imal a d m to d c ll d vi n will t b con dered her d t l S CELL DIVISION; MITOSIS

Th t le d u the vari s ph omena of g th f ll wed by ecti ns n eprodu t e gr th d m nan d ge mi atio per d c ty nd ab on a d ea on l th rmope dicity

Factors affecting plant growth Th facto h ch cont l pl nt gr wth can be epa ated nto th ee g up F r t a tl nhe t genet c fact s the ge e c rr ed by ll ell wh ch gi e e ry ell th pote t l ty t g w nd whi h c tr l th lim ts with n wh ch e h ell e g r a h pl t n dev l p (see GENETICS) The e l nt ll d ly by h e d g a d ce th egg ell s l rtil d the ge ti potent l t es of the l t e pla t a fi ed See REPRODUCTION PLANT

The d gr up of f t r wh h nt ol pla t g th the tern l f to uch a the inte a t o bet e ll th horm nal t ol st m th t nal f d di trib ti n a d all c lat on n g e l Th y w ll be d cu s d lat r th s c t on pla t h rm

The th l g f f et mpr the o t a d e al m nt

Th b la e b t the l ble w ter n the l d th w t r l thr gh t an p ti n one f th m j r fa t y la t growth (e PLANT WATER RELATIONS) An th maj one the a l b l ty f ut ts (s e P A T ITIVE AL 1 10 or) Th a f neti n f th on ntr t n f t nts the l a l l d p d n s h f t th l ter d t r th e f th t y r m th p nc of a p p s l m fi the t mpe t e l the il a d th l al b t th t nt S ROO (OTA Y)

F la d pl t tl a l m nt of pa am unt mp t n Th mp n t f this i m ta t mp t e l ght l um d ty w nd a mpo ti n d h t em e d t n a f t x es h t t m f b met s n ibl d t p i di ha g nd ch l g pl t d iml t th mmed t s u d g

It mp t t al how mpl th nte l t h p l tw xt rn l nd nte nal e i r m t Th ff t r b th d t d i di ect f l g g th r t n d l pme t fi tl h q t b h f the pla t a w ll At p nt k ledg ab ut the nt r l t hip b t th la t nl f gm ta y Th p tly l f th l ffi ulty f n t g t g ther F r In t d g th el t h p t y t nt l tl i rn l ment d t k w th g ti all un f rm pla t m t i l

Th s is n w be ng done i o c lled phytotrons in which each f the en iro mental factor can l e c nt olled epa ately

Th e add ti nal p blem f the irreg ilarities and u pr di t bility of the climate ar n deal ng with the effect of cl mat n plant growth The g owth re p n es of plant to ind idual factors w ll be d s u ed in this article

Plant hormones The cell i the smalle t un t of the organi m wh ch has all th att ibute of life nd wh ch an per i t s a un t See CELL (BIOLOGICAL) It ha been shown that n t only the f rtili ed egg cell b t al lat d cell from a ti e can grow and de el p int a compl te plant Thi wa already kn wn ab t certain l af cell wh ch up n egenerati n give r to plantlet on the exc d l af The efo f n t all at lea t a c ide al le n mb r of cells i the b dy f a plant wh n i olated an gi e ri e to a c mplete plant H wev r as long as the e cell a in co tact with the r n ghbo r g c ll n the i ta t pla t they d not h but th r f ll p t nt alitie l ut r ma n o ly a pa t of the wh l Thi me n th t there i a (n t olling me hani m nsid th pl nt wh ch inte g ate the indi idual ell th t ssu s a d the r gan into a omplete org ni m

It h s been p d in a n mbe f ca e that tl int r l t o s b tw en the cell wh ch m id them int a rgan m are due t mi ut amou t l h mi al p od ed i o e p rt of th pla t b dy wh h a t at r t hibit othe parts aft r th ch m l ha be n tran port d to th m S h h m i l p du ed in mall am u ts n ne pa t f the body and r gul ti g ther p t a calle h r m n In a im l t ho m n a e ar ed in the bl d t eam pl nts th are tr nsport d th gh the l ing c lls o i th t an pi tion t eam

If a ell i ompletely ff ent and c n p od ce all th tg n b tan e t n ed fo gr wth nd m t b l m u h a ll nn t b part of an rg n m M v u icellula algae can g w n th way lth gh th y m y d velop into irreg la m f ll (l ie) w th o w thout pe fe hap S ALGAE; CYANOPHYTA

In ye t i ght m d fi atio l th s g wth pat t rn x ts Th e lls a gr w p o i d d th c e t t on f me f th sub t nce th y p od ce th m l e h as b t n a d th am n i h gh n gh th l q d i wh ch th g w (s YEAST) Thu t gle c ll f yea t will not g w b t elf l t depend t on m y th r c lls t nd ng Onc e ugh b t n nd tl mi i prod d b all th ell they w ll st t to grow lle t ly

An o g m e ults wh p rt of the c lls h l t tl al l ty t p du e rtan t l ub t ce wh h a e t ll p od d by th r cell f th same i m Th s i p hap b i llu t t d th s f root g wth

Wh n oot tip l cm l g cut ff tomat pl t a d pla d pt ally n med um n t i of 2° g r olut n t wh ch the neces ary

mineral salts are added such a root tip will grow only a small amount But when thiamin in a concentration of 1 part in 100 000 000 is added to the medium growth is rapid Also tips of the cultured root when cut off and placed in fresh medium will likewi e continue to grow Therefore this medium contain all that is necessary for continued root growth In the normal plant the salts are supplied by the soil the sugar by the photosynthe izing leaves and the thiamin by the younger leave See LEAF (BOTANY) PHOTOSYNTHESIS Thus the roots cannot grow faster than the production of sugar and thiamin in the leave allows and as a result balanced growth occurs

In all excised roots investigated addition of thiamin is essential for continued growth In other roots additional substance such as vitamin B_6 and niacin are also e sential (see VITAMIN) Thu thiamin satisfies the definition of a plant hormone and vitamin B_6 and niacin may al o be hormones in such ca es as pea roots

There are many other hormones invol ed in the growth of a flowering plant For example if the stem tip is cut off the stem underneath stops growing in length But when the stem tip is replaced or when auxin the stem growth hormone is applied instead of the stem tip growth of the stem is resumed The amounts of auxin produced by the tem tip and required for normal growth of the stem itself are infinitesimal (about 10⁻ mg) and this places auxin in the category of hormones See AUXIN

Growth correlations A number of the correlations which exist in plants and which are usually influenced by hormones are shown in Fig 1 Young l ave grow becau e purines such as adenine are supplied to them by mature lea es Similarly an unknown growth factor produced by roots is es ential for stem growth It is not known where gibberellin or kinetin (a recently di covered plant hormone) fit into this cheme but it is clear that the growth of the different plant organs is intimately interrelated through the need of some plant parts for substances produced in other parts of the plant (see GIBBERELLIN) Often the e substances are simple compound and may be effecti e by being prosthetic groups of enzymes and the latter could not function without such groups See ENZY IE

In an unexpectedly large number of ca es the correlations in plants are produced by one simple ubstance called auxin which was first disco ered as the plant growth hormone which causes elongation of cells Now another ubstance has been found gibberellin which more spectacularly influences elongation of stems leaf stalk and leave It is present in plant organs but its role in normal growth has not been e tablished

Other correlation effected by auxin are (1) control of lateral bud inhibition by the apical bud (2) prevention of absci sion of a leaf petiole or of a peduncle of a flower as long a auxin is produced by the leaf flower or fruit (3) root for

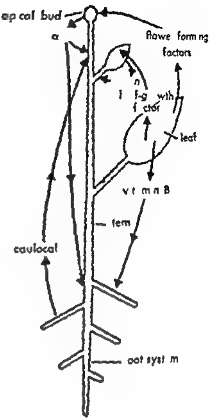


Fig 1 Schemat c d aw g of a pla t with oot sys tem st m old a d young leaf a d ap cal bud Some known gr wth co elat ons draw with b oken l es wh h ind cate factors re pon ble fo the correl t o Suga nterrelat on not hown (From F E Mo lto ed The Cell a d P otoplasm Sc ence Pr s 1940)

mation at the ba al end of cutting (4) ti ue growth and induction of cancerous growth (5) induction of xylem elements in regenerating vascula bundles and (6) production of parthenocarpic fruits See BUD (BOTANY) CANCER (BIOLO Y) FLOWER (BOTANY) FRUIT (BOTANY) VA CULAR BUNDLES

To explain how auxin can take part in o man rea tions and can control o many correlation it has been assumed that auxin controls one ma ter reaction in ol ed in each of the abo e-mentioned pro e e This ma ter reaction has been variou ly assumed to be a change in cellular permeability a step in c llular re pirati n a synthetic proce or a stimulation of transl cation of other ub tances but thus far n such universal master reaction has been found Re ar he s are till looking for the mechani m f each of the ab e mentioned proc e e

Embryonic growth After fertilizati n of the egg c ll b y one of the perm produced by the generative n icleu of the pollen tul e the re ulting zygote tarts to develop Thi occur either immediately after fertil zation as in mo t rapidly developing eed or after a d lay of e eral month as in the case of p nes S SEED (BOTANY) During the first 5–10 cell di is ons an undifferentiated mass of more or le globular t s ue i produced within the endosperm In d such as those

f or l ds de elopm nt does not pr c d imm iately beyo d th s point E e after g rmination of r h d e ds th glob lar cell m cont nues to gr w nl in all di ecti ns until b dy n to e al mill meter i diamete pr du ed whi h all d the p t c m D ff rent ati of tem and r t is delayed nt l th pr t co m ha eached th size wh ch take s l m nths See STEM (BOTANY)

I m st plant th d fferent ated ell ma de ed f om th zyg te pro e d di e tly to d ff r t te i to an mbryo o sti g of a growing t m up be ring two or m re leaf primordi t one end nd a t p mo d m t the th r Food for the gr th nd d ffe e t t n of the emb yo s uppl ed by th m th r pl nt e the di e tly fr m th tyledon o ind ctly by mean of the endo p m It has been f u d that the f lly dev lop d embry l ed d ult ated asepti ally n a m d m e nta ing ug r nd min r l H wev n imm t re mbryo eds in add t on mall am t f rg n utr nts such as ta m n A st ll sm ller mbryo n whi h only the be g ng of th c tyled n s i d ated w ll ot grow when ex d u l s t is uppl d with o on t m lk a ry r h o re of o g m t nt be g a l q d ndo pe m t ell

A n the mbry i d the e d s fully gr wn it pas nto a d m nt condit n wh h i br ken ly upo germ n t The m t ma k ble m whi h the mbry diff fr m all th d v l pm tal t f th pl nt is its ab l ty with ta d im t complet dehyd ati n a c d t n wh h e d th at ny th r tag n th l fe of the high r pl t

Vegetative meristematic activity Th t m p mord m f th embryo p n g rm at f th d immediat ly be om th w g st m t p h h nt ue t pr d e m tem ll d l f pt m d Th e s a em kabl ntr l f th ll d n th g wing p nt be a e th equ f l a f ll ws a p fect d r (phyllo- t) wh h t g lar ty mp e w th that f th tr tu f a ry tal

Littl kn wn t ut ntr l f th c ll d n th gr w g p t in g al l ng d v a e u ally eq d t k ep th ell d d ng n th s grow ng point e peci lly h b and t e f tempe t r g It ha t be po bl to h g th th p tt rn f th t m gr wi g po nt p c l m n t m wth hemi l M ru g th s i n e f m od ect n ha h w th i th j ng t le f p mo d ha e n i ff c th lo t l the ub equ t p m rd Th that the ell n the gr wi g po t al tho gh emark bly t n m u the g wth to com tent d p de t p e h th Th s i p hap be t i d t d by th ex t nc f ect l a d pe ich l hima s (growth di tor t n) Whe tw d ffe ent pl epec e e g afted t g th a new pla t oc a ally de el ps o th juncti of the r t su wh ch combi es th pr pert f both Th happens wh w grow ng point regenerate at the graft union which is compr ed f cells of both sp cie If the two hal es of the growi g p int are d fferent a plant re ult in wh ch the two species a e j in d lengthwi e An example of uch a ectorial ch maera i hown in Fig 2 Alth ugh there is a c n iderable difference in si e and g wth rate between the two speci comp ing this sect rial chimaera—for example a n ght hade a d a tomato—wh n in direct o t ct w th each other the cell in the gr w ng p nt and all along the stem grow a d a t in uni on that is they di d nd el ngate exactly the s me rat

Perhaps e n mo e remarkable a the p r clinal chimae as They have be n tud ed in greate t de ta l in the c se f n ghtshade a d t mat Occ si ally a b d dev l ps on the graft un n of the e two species that produ es a pl t in wh ch the cha a te s of b th p ci ar perfe tly bl nded a d n which the lea es fl wers and f uit are in termedi te between the two spec e in ze f rm nd c lor No actu l fu of the nu lei of the two spe ies has occurred this is hown by the fa t that a eed pr du d by these i te m di te fo m de el p e ther nt a ghtsh de or a t mato plant Th o gh ch omo me count and ther e iden t wa f u d that in the e p r linal ch ma r the d fferent layer of ti ue uch as the ep d m s the ortex a d th centr l cyli der (tele) bel ng to the tw d ff ent pec es (s e CORTEX PLANT EPIDERMIS PLANT STELE) Either the ep derm or ep de m s and c rtex bel ng to n pec and the cortex and e tral yl de a central cyli d alo b long to th other pe ie Th is po ible b ca e in the grow ng po nt th re ar thre lay r of c lls the de m togen wh ch g es ris to th

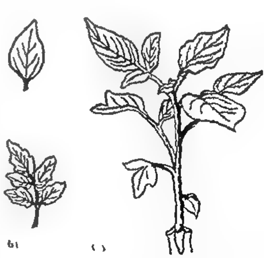


Fig 2 A t l h m (a) L af f bl ck ght h d S l m g m (b) L af f tom t S l m ly p c m ( ) B se h w t m t t m t wh h w dg f n ght h de t w s g ft d Aft f the tw t n h ot d l p d wh h o st d f ght h d t (ght) d f t m t t (l ft) (Aft W kl)

epidermis, the periblem which produces the cortical cells (outside the pericycle), and the plerome which gives rise to all the cells of the center (stele) of the stem from the pericycle inward (*see* PERICYCLE). All four possible periclinal chimaeras between nightshade and tomato have been obtained in extensive grafting experiments. Such periclinal chimaeras are also known for hawthorne, *Mespilus*, *Cytisus*, and *Laburnum*, and in each case intermediate forms are produced. This means that all cells and tissues influence each other during their stages of growth so that each partakes of the form and size of the other. In general, the cells produced by the periblem have the greatest effect on the final shape of leaves and flowers.

Similar periclinal chimaeras were produced in *Datura* by colchicine treatment of the growing point (*see* COLCHICINE). This causes formation of tetraploid cells. When only the dermatogen or periblem or plerome cells of the growing point are tetraploid and the others are normally diploid, periclinal chimaeras are formed in which the difference in cell size does not result in distorted plants, but gives rise to harmonious structures.

Occasionally a growing point enlarges beyond its normal size. This can be stimulated by auxin treatment. It then gives rise to fasciated (flattened, malformed) stems with abnormal phyllotaxis (leaf arrangement on the stem).

The stem growing point can be cultured in vitro by placing it on an agar medium containing sugar and salts. It will then develop into a stem with leaves which, upon regeneration of roots, will become a complete plant. Growing points of monocotyledons and ferns (which groups usually do not regenerate easily) are easier to culture than growing points of dicotyledons (which have a much greater capacity for regeneration).

In addition to the apical meristem, there are the lateral meristems in the plant called the cambium and the cork cambium, and the adventitious growing points. About the physiology of the cambium it is known that its activity is under the control of the buds and leaves of the plant. In deciduous trees, divisions in the cambium giving rise to phloem and xylem cells start as soon as the buds become active in spring (*see* PHLOEM; XYLEM). During the period of bud opening and young leaf expansion the elements of the spring wood are formed. Later the presence of mature leaves causes the cambium to produce summer wood with smaller cells, thicker cell walls, and often fewer vessels. This periodicity in cambial activity gives rise to the annual xylem rings in the wood. This is not an autonomous periodicity, for when the leaves are removed the cambial activity stops. If in the same year more buds and leaves develop, new spring wood is produced, followed by summer wood, and an extra complete annual ring is formed.

It has been found that auxin application to a stem can stimulate cambial activity in the same way growing buds and young leaves do. Therefore it is likely that the spring wood is formed under the influence of auxin coming from the buds and young leaves. Actually it has been found that the auxin production of these growing plant parts shows the same cycle as that of cambial activity. Also in most cases cambial activity starts in the younger branches and is followed by cambial growth in the trunk with a time lag which approximates the rate of auxin transport from buds through branches to the stem base.

It has been possible to grow cambium cells in vitro. In most cases, however, they regenerate undifferentiated callus cells, indicating that the stimulus for cambial growth is normally more complex than merely an auxin supply. This is also indicated by the periodic changes in the cells differentiating from the cambium. For example, in a rubber tree (*Hevea*), at intervals of 1–4 months a layer of latex vessels is produced in the phloem, alternating with layers of sieve tubes and other phloem elements. Or in the xylem of members of the plant family Sapotaceae, layers of wood parenchyma alternate with layers of vessels and fibers. *See* PARENCHYMA.

REPRODUCTIVE GROWTH

Reproduction in plants can either be sexual or vegetative (asexual). Some reproduction mechanisms which exist in higher plants are discussed here.

In plants such as *Ficaria*, some lilies, or *Hydrocharis*, many axillary buds swell and store food in their bud scales. These buds may then become detached and behave like seeds; that is, when conditions become favorable these buds start to grow and form new plants. In *Hydrocharis* or *Stratiotes* the buds are formed in autumn as a response to the shortening of the days, and they germinate only after having been subjected to cold during winter (*see* PHOTOPERIODISM IN PLANTS). In most bulbous plants, such as tulip, hyacinth, daffodil, and onion, reproduction is mostly vegetative. The bulb consists of a markedly foreshortened stem on which thick scale leaves are implanted, and when completely developed the stem usually ends in a flower. Toward the end of the season one or more axillary buds on the foreshortened stem develop into new bulbs. This causes the clustering of bulbs on the plant. When the scale leaves of these bulbs are halved by cutting off the upper half, a large number of adventitious buds may form on the cut surface, each one producing a tiny bulb which can grow into another plant.

In a number of plants thickened buds or bulblets are formed in place of flowers. Some plants, such as *Polygonum viviparum*, reproduce entirely in this way. In others, such as *Agave*, only occasionally do flowers fail to develop, but the flowers are replaced by such vegetative bulblets. The factors causing this transformation are unknown.

Very peculiar forms of vegetative reproduction exist in the genus *Bryophyllum*. The Madagascarian species *B. tubiflorum* and *B. daigremontianum* produce, under long-day conditions, adventitious buds in the notches of the teeth of their leaves.

buds dr p ff when they have f rmed the r
pa s f l a e t nd f rm n w plants
c lves n m th e h d ar f med n the l f
nly ft r th l af is nt ff
l mb r f plant fo ampl s a d
f rm ro t t cks which bra h a d f m
egr d sh t at th s p es As th lder
n f th oot t k d th g n l pla t b
d v ded t mbe f nd dual t
nd e n qu ntly m ltiple Whe the
me r man ab egr u d they a e c ll d r
St a b rries d m ny g es multiply th
R n er f rm ti n n the trawb r y t ctly
g d y r p d e u at high t mp r

p t toes u d rgr u d runn r larg t the
p d e ng t b Th t be fo m ti n the
lt f ti l s (r p haps horm) wh ch
es f m th h t d p du d ly t l w
p r tu r s h rt da s Th s t m l can
th ugh a g ft Th t le wi h a
med re d rm t nd t p nt equ the
h m c f t tm t w th thyle e hl hyd s
al m th f d rm ncy at r n temp a
e Th n u tat pr du ti n the
nt rs the ld w te d rm t tube
d w ho t d elop th ne t y g In m ny
h pla t h a dat l a a d w t p tato r ts
ll th m m n the u d rgr d h t
of the p tat d gr wi g p t th
t de l p t w ho t th foll w n
Wa y agr ult l e e re, odu ed eg t
ly f dd t t p tat e w t p tato a d
whe s the e uga wh h w fr m
m utt g A utt a p f t m th n
r mo n d wh h wh n pl d nd u t bl
l ti n (m t u u lly partly b d n l
d pe t) w ll p du t d b t o
t a mpl te pl nt lt M ny th pla t
h a Lomba dy p pl a d ma y hr b nd
ee gr w by h tic lt t p p g t d by
tt ng (St s cutt s) The oot wh h
d l p th utt the a f m p
med t p m d pe nt a th d
uga n w f mat m tl
th b l t d f th utt g Th t f rma
t s n xp f th t d y f a p t of
pl t t g n t f t Th h m n
es ry f t f mat d r ot g wth r
med th hoot d lls flow d nw d t
th t Wh th d n d t a p t nte
rupted by u g th t th h m a
m l t th t f wh th t m l t
w f rm t f oot It wa f u d th t n th
maj ty f a es th t m l f oot f rm ti n
m g f m th pl s r p be pl d by
th a p) tt t th b e f th
tt g ry mm ly pr t ed b h rt l
t t s u e good oot g Th u m t
n ta peed p oot g l g p op rt
f the utt g I m t m m
d l f nd t m l t oot f rm t n
A tt ts

In ca e s which c tting w ll n t ro t plant may be propagated by layer ng b dding

Floral initiation and development At a ce tain mom nt in th de el pm t of a egetat ve gr w ng po nt the regular q n e f egetat s ell d s s n interrupted and the gr wing p int tr f rm d i t a flow r pr m di m Th cha ge s ind ced by tim lu re ei ed by the l a e a d tran m tt d tl gh the phl em f the tem It can n w b t ted that when a pur ly get tt e ci n g ft d o a ph t p r di ally s d ced t k th ei n will nder c rt s ndition b a ther m al f tl l rger le f m ci n st tt t fl we *See* GRAFTI G OF PLANTS

Morph logically the fir t change n the tran f med g wing p nt is a br ade ng Then in ste d f th *regul r leaf phyll ta s th pal* are l id d wn sim ltaneo ly u ally wh l Aft r a t m t t n l of a f w d y anoth r wh rl of prim di the pet l a e formed Then the t me nd e p l *re p* d ced In except n l ca e th q e s partly e ed for ex m pl in th ca f s fl r n the flow r p rimo d r pr d d ac opetally (fr m th ba up wa d) o ba ipetally (*fr m the p x d wnwa d*) n the larg m r tem tt d me *See* I FLORES CENCE

The tt at f fl wer p m d a s n t e clu s ely u d th t of f th ph t p nd In m ny a es a t beet and pea h fl we in t ati nly fte ld t atm nt ll d e nal za t n This s n t du t n phen men b t th r *m y be n terv l of ne t e al m* th be *twe exp u e t ld* d t a f mat n f the gr w g p nt Wh n d g thi d ct p rod th pl nt ubject d to h gh t mpe atu s o ca si n lly d *rnal tt* cue with ltant no *flower ng* In m y pl t h de id o s tr e fl e nd the d o ch d (*De d bium men t m*) th fl wer b d dev l p o ly t a certa n ze a d th n b ome d rm t It the take exp u e t lat ly l w t mp r t r s to break th d r ma y f the bud I pea h s p a d the *de d t tl* buds n d a period of we ks o mo ths b l w 40 F b f r they w ll ope That me th t th y h t p thr ugh w t lo be t fl w g In th do h d ap d c l ng f m 80 t 65 F w ll mak th d m nt fl we b d nla g nd x tl 9 day l t r they op n In c f fe the fi t heavy *ra of th* a us ally t g g the fl we b d *de el* pme t nd 8 day l t r ll t ee wh h h c t ed th ra n w ll be f s t d w th flow

Flower biology The p *g and l* g of flow d the *pro e of p ll n t* n a f ati g fi ld f tud Wher s many flowe s h s m lli pdr g n a d o h d p nly d th n r m op f r th est of the l fe f th fl w ma th flower h tul ps popp t ha nd g a p n nd cl e ev e l t m with d l hythm On cl d y the Cal f poppy p t fl w t 10 A M a d the pet l l e n at 4 P M O th me d y

the tobacco *Nicotiana affinis* opens its flowers at sunset and clo es them the next day at 9 A M The flower movements of the California poppy are in duced by the light dark change of the previous day they close 21 hours after the previou sun et The flowers of the night blooming cactus open 24 hours after darkening on the previous day Tulip and crocuses open upon a ri e in temperature and close again upon cooling gazania flowers open above 18 C and clo e below thi temperature These responses to light and temperature are so regular that the time of day or the air temperature can be told fairly accurately by observing which flowers are open or closed It is actually possible to use flowers as clocks Carolus Linnaeus the great Swedish botanist planted part of his garden as a flower clock

The life of flowers varies from a fraction of a day to a month or more There are several factors which control the life span In many flowers the petals are absci ed (dropped) as in poppies and pelargoniums in others they wilt as in cacti and orchids Wilting is the result of lo s of vitality of the cells of the petals either because their sugars have been respired as in *Chrysanthemum* or be cau e their proteins have decomposed as in cacti (see PLANT RESPIRATION PROTEIN) In others such as orchids the auxin released by the pollinia cau es wilting

Most flowers have mechanisms for cro s pollina tion many are actually self sterile Sterility in flowers may be the result of a large number of fac tor such as genetic block (especially in triploids and others where abnormal meiosis occur) lack of germination of pollen insufficient growth in length of pollen tubes as in the long styles of *Oenothera* or corn or lack of chemotropism which i attraction of the pollen tubes to the ovules

Pollination in mo t commonly effe ted by flying inse ts which are attracted to the flowers by color or smell In many flowers the development of odor is periodic In the night blooming ja mine and in tobacco the flowers open at sun et and at the same time become fragrant the odor disappears again the following morning at about the time the flow ers close Other pollinat rs are ants humming birds or bats

A large group of plants such as ragweed grass s conifer and trees with male flowers in catkins in pollinated by wind their flowers are usually inconspicuous Their pollen di charged in large amounts i a major cause of hayfever

Pollination by mechanical means is ometime required when the pollen does not readily come ut of the anthers for example the shaking of the flowers of tomato Very rare are ca es of pollina tion by water (the male flowers of *Vallisneria* float on the water and thus their open anthers come in contact with the stigmata of the female flowers) In a few cases the pollen is ejected by the snapping open of the flowers as in *Pilea*

Mo t intere ting are the honey excreting nec taries (see SECRETORY STRUCTURES PLANT) These are usually found at the ba e of the flower or in purs (over 1 ft long in *Angraecum sesquipedale*) or sometimes outside the flower on bract as in the plant family Marcgraviaceae or in the genu *Euphorbia* This honey is excreted by pecial gla du lar cells or it is pre sed out of the phloem The pollen in insect pollinated flowers is u ually t k because it i covered with a waxlike material

Many flowers show marked movements before opening or after pollination for example poppies and *Linaria* The e movements are u ually due to differential growth of the two ides of the flo er stalk cau ed by auxin See PLANT MOVEMENTS

Fruit development Auxin plays a very im tant role in the growth of the ovary after poll a tion The pollen it elf provides the auxin in the auxin is produced in the fertilized ovule There fore an ovary of a nonpollinated flower u uall does not enlarge but if treated with auxin it ma produce parthenocarpic fruits uch as seedle tomatoes or watermelons It was found that in the naturally parthenocarpic fruit of the navel orange the pulp in the developing fruit provide the auxin neces ary for growth Auxin application will onl lead to the formation of parthenocarpic fruit in lo temperatures during the middle of summer it ha no effect

If every flower grew into a fruit mo t plants would not be able to support the crop Howev r many flowers drop off before fruits start to grow and some of the growing fruits al o fall Auxin sprays are sometimes effective in preventing fruit drop at present uch sprays are generally applied to prevent the preharvest drop of apple

As a fruit grows its total respiration increa es until it is almost ripe then respiration decrea es In ome fruits for example the avocado a so called limacteric rise in re piration occurs h n the carbon dioxide production more than doubles just prior to the fully ripe stage howe er this happens only after the fruit is picked off the tree

DOMINANCE AND GERMINATION

Every leaf arries a bud in its axil which ca grow into a hoot ith leave and bud Like i e each of these buds in its turn ha the potential of growing into a leafy shoot Should this happen the plant would oon become an inextricable clump of branches Although it does not occur naturally there are ertain d ea es which cause every ax l lary bud t grow For example a fungus causes the de elopment of mas of small branches called wit hes br oms in tree

Apical dominance In a normal plant only a mall per entage f the axillary bu d grow int a hoot When for one on or another the apical bud ceases gr wth a few axillary buds lower d n the tem will de el p This suppre ing effect of the apical bud on lateral or axillary buds i called apical dominance For ome time it had been pected that the apical bud exerted its influence through the production f a horm nelike ub stance After auxin was di red to be the stem

g r n horm ne p duced in th stem t p it l n shown to be the mate ial pr duc d by the l b d th t is espons ble fo nh b t n of ax l y b d growth Rem al of the ap cal bud e th i h bit n but replacem nt of the ap cal l w th a adequat a xi supply r st r s th al bud h b tion H we e only a few h ur rupt of the a xi supply reles e the lat l bud nhib ti n i r ve bly

Ap cal dom n nce h s m ny ntere ti chs ac F r tan e th inhibition r a s wth ta e f om the tip nd th b ds farthe t re ed fr n th ap c l b d re most nl ib t d her a the bud ne re t to it ha e th e b t chance dev l pment Upo emo al of the ap c l bud upp rmo t x llary b d t t t grow o ce y tart gr wi g th y inh b t b ds f rther d wn n th t m t p

In at r c nd t on oc u under wh ch the ba al d g w more than th e nearer th p For e mpl afte a wa m wi t pea he how de ayed fol t o th t s the ap cal bud fa l to pe spring and b d l we d wn the tems r the b nes h ch gr w

M y hypothe es ha e b e offe ed to expla n he me ha i m f u n a ti n n l teral bud i b t Th d re t ct on hypothe s stat s that th is m r ly a m tt f au i e n entr t n at l w nc t t aux n c el r tes t m g with t h gh nt at t i b bits g wth How er th d n t a c nt f the ll n ne natur of nh b ti n B sid it h be n sh wn th t t not th t t l am t of x n b t the r lat amounts b d nd i m that tr l gr wth O ly when th u t ti n the bud e ds th t n the d t m b d g owth p s bl In mewh t d ff nt l ght the hyp th of d r ct t n m that auxi r l s nhib t s o nt l t n po t f ther nt l growth fa t

Ap l d m n n a app r the w s In f r the p pend c l growth of th p im y hoot s all d th ir p wh ll l t al hoot gr w m le s hor tally pl g o t p lly Wh th ap x i em ed the p cal b d nj ed m f the h gh r ide b a hes w ll be m rthotr p nd tak o the t l po i o d f ctn n f the o g n l ap al b d Th u p n s a d fi b t *A uc n* th pl g t p e gr th f the l te al h t n t p n i th d m e f the p cal b d f th y ma pl g t p es n t the ab e f p ll d

Bud dormancy A pl t d pr ly th m j t f bud d t g ow b a e f the l t h b t tabl h d by th g th of the ap l b f A soo th el t nh b t r m ed m f th x ll ry bud beg t gr w ally th f w d y M bud d n t ct t w wh th g ng c l to l c m f bl e d wh p l dom t m d lec l bud d rm nt D m nt l d or r o m t d d u gl t i w t

When a lilac oak peach branch is cut off a pl nt g owing outs de and brought int the green hou the bud will not develop betw en Oct ber and Febr ary In Apr l r even in early summer th e plants ha e nond rmant buds and they start to grow a oo as the b anches are remo ed and the cut ends p t i a mo t medium Dormancy of th bud i ndu ed by the short day light exp sur of the br nche in a tumn Wh n u b de iduous t ee are kept througho t the summ r under l ng day c nd tions the r bud do not become dormant and they will develop at an time when th tem per t r is f v rable and the c rrelat e inhibi ti n is remov d

I duced bud dormancy can be l oke in e eral ways In nat re it i done by expo ure for everal mo ths t near freezing *temperatu e* . *Peach* or pear tree b ought into the greenhou e in l te a m m r r a tum are dorm nt and they ca rema n do m nt for more than a year becau e th buds ha not b en e posed t old The bud it elf m be kept cold On branch wh h has be pa tially ooled nly the b ds on the c ol d part de elop

I a numb r of ca es a chemi al treatment can sub t t te for the cold requ reme t and ethe or thyl ne chlo ohydrin pors a w ll a n tr phe n l and thyl e ha e been u ed t b e k bud dor mancy Chemi al tre tments ha the ad antage of r qu ng only few d ys n c ntra t to the cold xpos re wh ch mu t la t weeks r months

Bulb and t be commo ly have t g th ough d rm nt d b f they can sprout In some c e th is a qu t n f tr ight dormancy (glad s p tat l ly-of the- lley) n wh h c ld r ethyl ne chlor hydr n w ll b eak it Other a s w ll be d scu d i th rticl i the se t on n e al t rm pe d ty

Germination I t e s tion on *embryon c* gr wth th f rmat on of the d was desc bed and t w t t d th t up n ipen ng th e d p s i to d rmant c nd ti f m wh h it m rg s up n ge mi t on

The s ed repr e t a tage in the d velopment of a plant wh h i part ularly istant t cold he t and dr ught The main f nct n of a eed is t pro d f p geny by arrv ng the pl t o er unf v rabl e d t on and f l tating d tr bu t n of th p es

In germ nati n three d ti t tages e b dis gui h d The fir t st g mp es th ntake of ate a tag that i ompleted wh ll ell walls a d p otopla t h suffici t wat ntent A o- ci ted with th water uptak s an cr a n r at n The eco d tage is a cu o n Except f re pi ati n no m u able ch nges c r the embry d not nl a d the d to be n d t n f u pe ded n mat n D ring th e fir t tw tag germ ti n s eve l l p o th ed n b d ed nd e tted n mb f t m s with ut a y ff ct on the futur g m abl ty Large n mbe f se d per t f y r ev n d d n th o l w th t e ch g th th d t g f t al e la g m nt f th em

bryo However once this third stage has set in there is no holding back and the embryo goes through its exponential growth to form the seedling or it dies

The second stage that of suspended animation is the most critical because it is the period when it is decided whether the seed will germinate or not it is an all or none process No matter how long or short this second stage of germination lasts once the inhibition has been released growth of the seedling will always be the same

Some of the mechanisms involved in preventing growth of the embryo and the events occurring during the second stage of germination can now be discussed

For a number of seeds it has been established that they contain substances which inhibit germination When such inhibitors are removed either by decomposition or by leaching embryo growth proceeds normally In at least one seed *Amaranthus* and probably in many others such inhibitors also repress respiration Thus *Amaranthus* seeds can be kept for many years in moist soil without germinating or utilizing all their storage food

In other seeds it has been found that the seed coats or certain layers of them are impermeable either to water or to oxygen Breaking (scarifying) of such impermeable layers leads to germination

In many leguminous seeds in which the seed coat is so hard that the embryo cannot break through scarification suffices for germination

In the seeds of wild plants a large number of mechanisms delay germination until the growing conditions for the seedling are favorable Cultivated plants are not sown until the season is proper for germination and growth consequently germination delays are unnecessary and may be unfavorable The germination behavior of seeds of cultivated and wild plants should be clearly distinguished

Many seeds fail to develop and ripen under conditions which seem unusually favorable for germination such as the moist interior of a melon or of a tomato fruit In such species there are substances in the fruit pulp which inhibit germination In exceptional cases however germinated seeds are found inside the fruit for example occasionally in oranges or peaches

Some seeds of northern crop plants such as barley and wheat germinate at low temperature and can be sown in autumn or early spring Others such as corn sugar beet and tobacco require higher temperatures and are sown much later in spring or they are sown in greenhouses and the young seedlings are transplanted in the field for example tomato and chili pepper The latter plants originated in warm climates and grow only during the summer

Seeds of tropical forest trees usually have a short life and unless they germinate immediately they decompose in the humus layer

Many seeds which normally remain dormant during winter need stratification that is treatment with low temperature (near freezing) before they will germinate This treatment is effective only when the seeds are moist

Most of the seeds which have inhibitors hard or impermeable seedcoats or need stratification before they can germinate have normal embryos which will start to grow as soon as conditions are favorable There are other seeds the embryos of which will not develop even when excised Such embryos are either immature or have embryo dormancy In both cases germination can occur after a sufficient period of waiting during which after-ripening (physiological change) takes place

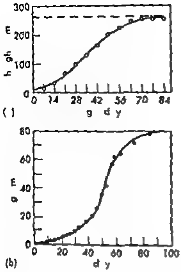
The seeds of many plants germinate very irregularly only a few at a time In this way germination is sometimes spread over a period of many years with occasional peaks of germination at about yearly intervals

Seed germination of desert plants has been studied in some detail The seeds show a number of different mechanisms which prevent premature germination When rains are few and far between the chance that a small amount of rain will be augmented by another rain is slight Under these conditions germination in desert plants would best be delayed until about 1 in of rain has fallen continuously and when the soil is sufficiently wetted to ensure normal development of the seedling Some seeds have four or more mechanisms for delayed germination Among these belong (1) presence of germination inhibitors which can be removed by leaching as occurs during a heavy rain (2) excess mineral salts in the seedcoat or in soil also removed by heavy rain (3) remains of fruit covering which have to be removed before seed can germinate and (4) hard seedcoats which may be removed by scarification usually by rolling of the seeds with sand or stones for example after a heavy rain a slurry of water sand and gravel rushes down the wash carrying with it the seeds of smoke tree palo verde and other shrubs

Growing plants have a strong inhibitory effect on seeds present in the soil around them Germination of many plants does not occur in a closed vegetation Interesting exceptions are seeds of parasitic or semiparasitic plants such as *Striga* and *Euphrasia* Their seeds germinate only under the influence of excretions from the roots of their host plants The reverse phenomenon was found for the guayule rubber plant *Parthenium argentatum* whose seedlings are killed by excretions consisting partly of cinnamic acid from the roots of the mature plant *See* CARBOXYLIC ACID

PERIODICITY AND ABSCISSION

There are relatively few plants which grow without periodicity Basically all processes in the growing point are periodic for example the laying down of leaf primordia is cyclic and occurs in a definite sequence producing a specific phyllotaxy



g 3 ( ) G wth h ght of fl w t m (f m Od m F d m t I I E I gy S d 953) (b) G wth f t pl t m d y c dry w ght (f m Gu B km ft f f w k D W Th mp O G wth d m C mb dg 1942)

Growth periodicity E h d v I I fl a d h t d g th ugh succ o f g wth t th o- ll d g nd pe od f gr wth Whe h f gth f ell o f an nte n de ı e o d d s a f t f t m gm d (f) rv b ed h wı g th t fte an n tıal l w r t ; th ı c a es t a ma ım l at d th n g ad ı lly d a (F 3) Th t p al f th I d I II I a c l of ll h a a b l r ye t ltu e d v n f wh l m Be a g w ng pla t u llv ha th me mb f d d g gr wı g a d m tu ng ell t t m the g wth te f a wh l t m egul d l n a al ays m t ı g th s m p p t n f g w g c ll n th ı d ffe t t g Thu th g lar g owth r t f th wh l pl ı th nt g t f th nd f mo d g th rv f th d d I ll

A a expl d ı th tı d ma y th p d ty of g wth f f p h t e p n lly d ed b th xt n l nd t B t b f pl nt ft b d th m ph l gy f th pl I I tul p d th b lb u ı la t th g p nt goe th gh c l f f m ng f t l a e d flowe B u the fl t m n t th g w g p t a w ll v bud tak r nd a n w le st ted In th t m t pl t th am ph m c Aft f m g 8 I nod (d p d ng n th ı t ı th g w g poı t t n f rms ı t a t rmt l fl r Th n a ı t l b d ı rı t r w fo m 2-4 n I d l k w te m t n a fl w Thu th t m ı t m a ympod m (ma y f k d) a d d fi t p ıod c ty n de l pm nt a b b

erved In pıne pea hes and mo t other tree there ı a qu nc f f rmat on of n des bearıng le ves nd l ud cale E en ıf there ıs no ce a t on of gr wth whe the bud wıth bud ales ıs formed f r ex mple beca e the bud d d not be me dorma t as a re pon to h rt day tre tment the cycle of cale and le f f rmatı n ıs repeat d e ral t mes per yea g v n ı idenc of an ınter n l g wth per odı ıt

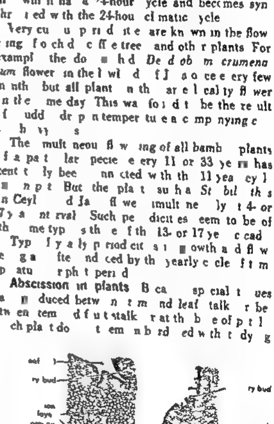
M ny ca es f pe ıod c ty ın de elopme t ha e been sh wn t be ı d ıced by extern l fact r The da ly fl tı at on of g owth rat s of tem root and l a es ha been fo nd to be lı at le t ı pa t to the daily l ght d rk cycle t th perı d c ıty ın t mpe atu r t the change ın r l tı e hu m d ty f m day t nıght How r ı th ny tına tı (sle p) m vement of l a es tl e ı also an a t n m u mp nent ın tl e e gr wth p rı dı wh h ha a 24-hour ycle and becomes syn hr ı ed w th the 24-hou cl matıc ycle

Very cu u p rı d ıt e are kn wn ın the flow e ıng f o ch d c ff e tree and oth r plants For exampl the do h d *De d ob m crumena tum* flower ın the l wl d f J a o ce e ery few m nth but all plant n th ar e l cal ty fl wer n tl e me day This wa fo ı d t be the re ult f udd dr p n temper tu e a c mp nyıng c t h vı s

The mult neou fl w ıng of all bamb plants f a pa t lar pecıe e ery 11 or 33 ye has tent t ly bee nn cted w th th 11 yea cy l n p t But the pla t su h a *St bıl th s* n Ceyl d Ja fl we ımult ne ly t 4- or 7 y a *nt rval* Such pe dıcıt es eem to be of th me typ s th e f th 13- or 17 ye c cad

Typ l y a ly p rıod cıt s ı owth a d fl w e g a fte nd ced by th yearly c cle f t m p atu r ph t perı d

Abscission in plants B ca sp cıal t ues a duced betw n t m nd leaf talk r be tw en tem d f u t stalk r at th b e of p t l ch pla t do t em n b rd ed w th t dy g



Fg 4 Ab ( ) L g t d l ct o th gh b of l f f P D f ll f m a b ss l y h w n lly (b V rt f t th gh p t f t m d l (b f C l ft b c o f th l f (F m R D G bb B t y A E l t ry App 8 l t n–M G w H ll 1950)

and dead leaves flowers or fruits (Fig 4) The e dead parts drop off (ab cise) and are regenerated to carbon dioxide in the carbon cycle of nature often before the whole plant has died and fallen to the ground

Although not much is known about how or why a leaf absci es a great deal has been learned about how to stimulate or prevent absci sion The abscission layer at the base of the petiole is formed when the leaf blade is removed or when the leaf is no longer active as in autumn The formation of this abscission layer can be delayed by applying auxin or other substances with similar physiological activity on the leaf talk tump

The reaction of the ovary and fruit is similar to the leaf When the ovules in the ovary have not been fertilized no auxin reaches the place of attachment of the fruit stalk to the stem and the young fruit ab cises The lack of the inhibitory effect associated with developing seeds can be replaced by auxin application to the ovary This means that auxin production by the developing eeds has at least a dual function cau ing the growth of the ovary and preventing its abscission as explained in the preceding section on fruit development

There are several practical applications of the e auxin effects One is the spraying of ripening apples with auxins to prevent preharvest drop and also to prevent bruising of the fruit as they fall on the ground Another is the u e of auxin sprays in tomato growing to prevent the flowers on the first clusters from dropping off and to cause the continued growth of the young fruit

In a number of flowers fertilization causes abscission of all the flower parts except the ovary this pre umably is al o connected with the auxin production by the developing ovules or by the auxin released by the pollen The latter is the case in the postfloration phenomena in orchids Instead of placing the pollinia on the tigma auxin can be applied and will produce swelling of the ovary and wilting of the petal

The mechanical cotton pickers work properly only when the cotton plants are leafle The efore methods have been developed to defoliate cotton fields This can be done either by killing the leaf blades hich will cau e abscission of the petiole as though it had been debladed or by applying an antiauxin

Not only petioles but also whole branches may be dropped through the formation of an abscission layer This occurs in *Castilloa* and in *Stercul a* and results in a self pruning operation in which the older branches shaded by the higher ones are abcised

Tissue culture in plants Under the heading of tissue cultures often the problem of organ culture is also con idered The growth of ro ts in vitro was di cu ed under the general heading of pla t hormones and the culture of growing point was treated under vegetati e meri tematic acti ity Typical plant ti sue cultures were achieved for the fir t time about 1938 When pieces of tem root or other organs are placed a eptically on an agar medium containing sugar and mineral nutrients they either regenerate buds and roots and grow a a complete plant or they produce a mall ma of undifferentiated ti sue called callus which develops into a globular mass on top of the piece of stem To make this globular mass of undifferentiated parenchyma cells grow to a larger ma s it is necessary to add auxin to the medium

Thus callus tissue transplanted a eptically in a medium containing sugar mineral alt and auxin will grow to a large ma s of undifferentiated cell This mass of callus can be subdivided into mall pieces and each piece will continue to gro equally well on this medium Whereas this i the rule occasionally a piece of such a callus cult re will lo e the requirement for auxin in the medium and will then continue to grow on a medium containing only sugar and salts This i called habituation and makes these ti sues less dependent upon their environment

Usually plant tissues are completely dependent for growth upon the surrounding ti ue and organs and such ti sues fail to grow when the adjacent parts become mature An exception exi ts in the ca e of crowngall an abnormal growth hi h u ually occurs near the root crown on stems Crowngall i induced by *Bacterium tumaefaciens* and it is largely a mass of callus It i po ible to keep the crowngall callus growing even when the bacteria ha e been eliminated becau e the callu ti sue loses the requirement for auxin in the medium It will grow in the same ugar nutri t medium in which habituated cultures develop Because of its independence of auxin it has e caped the growth control of the plant Thi expla why a crowngall develops

More recently a number of ub tance ha e been i olated and identified which increa e gro th of callus cells usually manyfold Many are pre e t in coconut milk Among them kinetin or 6-furyl aminopurine has been investigated mo t extensively

The mo t interesting new de elopment in ti ue culture is that it has been found po ible b ev eral different means to make a ingle callu cell devel p into a large callu mass and to ha e this differentiate into a shoot and ultimately into a complete plant Thus a single undifferentiated cell ha the potentialities of de eloping into the compl te organ sm just as the egg cell has

Usually no differentiation of tissu es and organ occurs in a callus mass Upon tran planti g a piece of differentiated ti sue into it ho e er a differentiat on of callus cells in the immediate i nity of the t a splant will occur

SEASONAL THERMOPERIODICITY

Temperature influ nces mo t phy iolog cal proc e e The optimal temperature i the temperat re at which a proce is f te t or m t effi ent Abo e the optimal temp r re the rate of th

oc s de r e ften rapidly s a res lt f n y t the p toplasm Th re al o a minimum mp tur bel w wh ch th pr e s do s n t g at ll I m y ca e th s low t temperatur 0 C r e e sl ghtly bel w fre z g B au e I mot c lue f th ell t t ells do not e le s cool d to well below 0 C (see Os osis) Ab th m m m tempe at the ate f the p e s n r a rapidly an e ponent al a mu h s t mp ature infl e ces the r te of hem al p c s Th m a that fo e y n temp at f 10 C th ate of th p c s is bl d or tr bled The rat f the p o e s at g ven temp atu d ided by the at at a temp r 10 C l w r s called the temp rat r oeffi t o Q M ny pl nts a n t dev l p n rm lly a t temp r tu e whe th da ly t m p ature ang s k pt w thi th am l m t F r exampl s g be t plat kept ev ry d y at 23 C d e ery n ght t 17 C w ll o t n e t g w getat vely fo 3–4 ye aft r wh h t m th l er ts away A pe h t e ca b k pt f r ma y ye r de the bo e m nti n d t mp t re re g m w th ut e r fl w Tul p and hya th b lb pl ted t th e en l mate of th t p t h gher altit de will ot d el p orm lly nd w ll d e t 1 2 y All th e pla t will de l p n rm lly wh n they e bje te l t a y ly cy l of low f llo d by high tempe t Th requ m nt c lled s so al th rm per d c ty

In t l p a d the bulbs the se n l th rm pe od ty h b n t g t d ng s t d ta l It was f d th t ea h d elopme t l t ge f the plant h t wn pt mal t mper t e When the b nd p rt f th tul p pl nt h ded th b lb mpl t ly fill d w th t g f d th l l nd th g w g p t ha form d ly f l f p tm d D g th n t few we ks m r leaf p m rdi a d fl w r p m d um p du d Th p e s f m ph g e l s a lat v ly high t mpe tu e pt m m l abo t 25 C (PLA T MOR HOGENESIS) Wh n th b lb b eque tly k pt at th t temp r t e ry l ttl l w ll h pp n Alth ugh lt m t ly a f w w ak l m ght pp a th flow t lk n l g r To make the pla t d l p n rmally the t mp r t e m t b l w d fte the fl w r p m d h e b n t ted By k p g the b lbs at 0 C th y n b t r d f r 6 m th l nge th t d mag f ll w g whi h th y n b f d to fl w p d c g tul p fl t y d t d m

At a m wh t h gh tempe tu e 5–10 C th b lb till m t r ma n d m t but wh n th y fl w d b ught t 13–17 C th y w ll p t p dly Th d t h pp n n th b lb k pt at 0 C It d t that p et tme t t 5–10 C f l m th ntt l f r l t g owth Th s 5–10 C a d l yed pt m m wh h th eff t bec mes app r nt me tim ft th t e tm t

Aft r th 5–10 C t atm t th t al pt al t mpe t f t m l g t b t 13 C n t l fl w r pe g wh n it shift t 17 C. In this way the follow ng equence f optimal te np ra tures ha been f u d f r t lip de el pment e ch la t ng 1 2 month 25 5 10 13 and 17 C A per od of 11 om g nd ph to ynthe i f llows after wh ch th ame t mperatu e q ence mu t be epeat d

F a hy c nth th opt m l temper tur q en e i 34 25 13 21 C I th t plant each tempera ture al o co ected with a specific pha e of de elopm t Th r f re the e bulbs mu t pa thro gh equence of diffe ent temperatu e to allow the ar ous m rph genet c nd phy i l gic l p o es es t t ke place In trop cal limat with c n tant temperatu e the b lbs d not p as thr ugh s ch s q ence and hence the plants do n t d velop n mally In a *temperate* cl mate with the pr p r y a ly cy le of tempe ature the l ulbs n t nly d elop p op ly but th y al become n ch m d with th cl m te

The e s a l rg mber f plants in temperate lim t s which ha e t th ough *cycle of* h h l w h *gh temp* t res w thi a p ri d f ab ut 1 ye l f re they d el p no mally In be t ca ots *and other* b enn al pl nt a low tempe atu p r od ti ne a y befo e fl we in tiat n a ccur late t h gher t mp rat re In dec duo s t es the l w r temp t r a e n ce ry f r l te flow r i t at n nd f r breaking of bud d rman y

Daily thermoperiodicity Practically e ery wh re i the w ld the temp atu d r ng the d y ex ds that d ing night It h s been fou d that pl nts gr w bette whe ubje ted t u h a d ily t mp r re *fluct* tio than when p o d to a co sta t t mpe t F m th l m ted amo nt of nfo m tion ailable it eem that a 6 C temp tur d ffe e t al b twe day a d ight about opt mal l de t pl nt this opt mal d ff ential s ms t b higher t m t pi al pl t t m y b l w

Only p rt of the e pl n t on f th phe menon l e i the d ff nt p c e wh h p d m n te i the pl nt d k nd light e ch with ts own pt mal tempe atu In the tom t pl nt for ta e m t g wth o rs d ing the n ght at an pt mal t mperatu e of 17–18 C D ring the day th pt m l temper t r b t 23 C wh h c in d s with th h gh ptim m of ph t synthes s

Th xpl n t o h weve a nts f r nly p rt of the d ly thermope d t) l m t pl nts it eem th t th t m s 24-ho r y l is of ramo nt import n f r n m l dev l pm nt If th nte n l y l d s not de with th a d f the e t r l cy l r of the xte nal y cl t y h nze th y l p ce n d the pla t de l pm t l w d w b c me bn r mal Thu th d ly t mperat re y l a d the l ght da k y le t d t t r de l pm t i to m l cha n l S PLA T PH Y IOLOGY

[F W W]

B bl g phy W Cro k *G o th of Pl ts* 1948 W Crock and L V B t n *Phys l gy of S d* 19 3 W E Loom *G th d D ff nt*

and dead leaves flowers or fruits (Fig 4) The e dead parts drop off (abscise) and are regenerated to carbon dioxide in the carbon cycle of nature often before the whole plant has died and fallen to the ground

Although not much is known about how or why a leaf absciss a great deal has been learned about how to stimulate or prevent abscission The abscission layer at the base of the petiole is formed when the leaf blade is removed or when the leaf is no longer active as in autumn The formation of this abscission layer can be delayed by applying auxin or other substances with similar physiological activity on the leaf stalk stump

The reaction of the ovary and fruit is similar to the leaf When the ovules in the ovary have not been fertilized no auxin reaches the place of attachment of the fruit stalk to the stem and the young fruit abscise The lack of the inhibitory effect associated with developing seeds can be replaced by auxin application to the ovary This means that auxin production by the developing seeds has at least a dual function causing the growth of the ovary and preventing its abscission as explained in the preceding section on fruit development

There are several practical applications of these auxin effects One is the spraying of ripening apples with auxins to prevent preharvest drop and also to prevent bruising of the fruit as they fall on the ground Another is the use of auxin spray in tomato growing to prevent the flowers on the first clusters from dropping off and to cause the continued growth of the young fruit

In a number of flowers fertilization causes abscission of all the flower parts except the ovary this presumably is also connected with the auxin production by the developing ovules or by the auxin released by the pollen The latter is the case in the postfloration phenomena in orchid Instead of placing the pollinia on the stigma auxin can be applied and will produce swelling of the ovary and wilting of the petals

The mechanical cotton pickers work properly only when the cotton plant are leafless Therefore methods have been developed to defoliate cotton fields This can be done either by killing the leaf blade which will cause abscission of the petiole as though it had been debladed or by applying an antiauxin

Not only petioles but also whole branches may be dropped through the formation of an abscission layer This occurs in *Castilloa* and in *Sterculia* and results in a self pruning operation in which the older branches shaded by the higher one are abscised

Tissue culture in plants Under the heading of tissue cultures often the problem of organ culture is also considered The growth of roots in vitro was discussed under the general heading of plant hormones and the culture of growing point was treated under vegetative meristematic activity Typical plant tissue culture were achieved for the first time about 1938 When pieces of stem root or other organs are placed aseptically on an agar medium containing sugar and mineral nutrient they either regenerate buds and root and grow as a complete plant or they produce a small mass of undifferentiated tissue called callus which develops into a globular mass on top of the piece of stem To make this globular mass of undifferentiated parenchyma cells grow to a larger mass it is necessary to add auxin to the medium

Thus callus tissue transplanted aseptically in a medium containing sugar mineral salts and auxin will grow to a large mass of undifferentiated cells This mass of callus can be subdivided into smaller pieces and each piece will continue to grow equally well on this medium Whereas this is the rule occasionally a piece of such a callus culture will lose the requirement for auxin in the medium and will then continue to grow on a medium containing only sugar and salt This is called habituation and makes the tissue less dependent upon their environment

Usually plant tissues are completely dependent for growth upon the surrounding tissues and organs and such tissues fail to grow when the adjacent parts become mature An exception exists in the case of crowngall an abnormal growth which usually occurs near the root crown on stems Crowngall is induced by *Bacterium tumefaciens* and it is largely a mass of callus It is possible to keep the crowngall callus growing even when the bacteria have been eliminated because the callus tissue loses the requirement for auxin in the medium It will grow in the same sugar nutrient medium in which habituated cultures develop Because of its independence of auxin it has escaped the growth control of the plant This explains why a crowngall develops

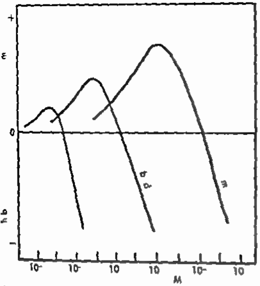
More recently a number of substances have been isolated and identified which increase growth of callus cells usually manyfold Many are present in coconut milk Among them kinetin or 6-furyl aminopurine has been investigated most extensively

The most interesting new development in tissue culture is that it has been found possible by several different means to make a single callus cell develop into a large callus mass and to have this differentiate into a shoot and ultimately into a complete plant Thus a single undifferentiated cell has the potentialities of developing into the complete organism just as the egg cell has

Usually no differentiation of tissue and organs occurs in a callus mass Upon transplanting a piece of differentiated tissue into it however a differentiation of callus cells in the immediate vicinity of the transplant will occur

SEASONAL THERMOPERIODICITY

Temperature influences most physiological processes The optimal temperature is the temperature at which a process is fastest or most efficient Above the optimal temperature the rate of th



G wth p f pl t o g t th pl t g wth h m d f ed (A C L p ld A d Pl f G wth U ly f C lf P ss 1955)

may oc t th r trypt m r d lepy u e d nd th nd l t ld hyd th mmed ate } ecu so to d l a ti d

It nte t g to te that th ym wh h hag the dol cet ld hyde t th gr wth h m d s e t rd ly e t e t rad t d m g Rad at n f pl nt with e the ut n r zing ad t o h a ay a e bl ck ge f th h rm n ynth z g t ty the pl nt p t d t by S A C d n in 1956

O e th g wt h rmo f rm d t m s bo t th ugh th pla t with d r bl p d f b t l em/h l a d th m me t h th r ma k bl q l t f b n p l th t th h m m e f m p to l Th m n t f th l the h mo th t ps of t ms the ng p nd g l d the p dly w g rg h fl w f t a d o t t p Th h m f rmed t th t th m dow th pl t n p l m n d d g o t p p ll imp es p la ff t pl t d l pm t F mple th p l m em t f th h m e f m th t m t p u th l l t f l t r l b d a d b h ld ng th m gr wi g f t n th t p f th pl r a d t g k g t h l t th d t f m th t p n a A th x mpl th horm f m d t th t p f t m fl n th a gl nd te of e th f l t r l b n h th th m a n th t m g f m th t m t p th m n l h z t l ll l th a gl f th l w l l d th l r p d th g wth f th l w b n f A t th r x mpl th h m sh th d ff nt t t f t wh e um l te t ath l m nt s th t wh t m led m ff d th r l r m m t of t t t upt d t w ll f m at th t of th nt pl n

Th r mu t l a way f r the plant to dispo e f th gr wth horm n and n fact there are at least tw p thway kn wn t pre ent by which the h r mone an l e destr yed or c n rted to anotl er product De t u tion of the horm ne can occur by x dati n Th can c m ab t thr ugh the action f h ht as an oxidant or thr ugh tl e a ti n f o t ing rad at o or s a con eque ce f oxidati e zym The be t k own en yme wh ch o d z s indole e tic acid i peroxida e Many r archers bel e e th t the bulk f the h m ne in plant is d sp ed of tl ough tle a t on f tl enzyme Pl nts g wi g in th d rk are ab n mally el n gat d b au e the ab nce of light re lts n le s u t o d t n tha in no mally ligl ted pl nt The c nd p thway of growth horm ne remo al f m the plant m y be tl ugh the f rm ti n of dd t n product Only ne u h add ti n pr duct has be n is l t d fr m plant n far a p pt de between ind lea ti a id and a part c acid There a i b l ly th r dd t on product as w ll When ind lea et c a d i f rmed in nimal bod e its de t u t n o c s ia the ame two cl em a d it i c eted n th urin the as an idation p od ct or a a peptide with n am no acid In fact th gr wth h rm n f plants was fir t d ribed as a mat r l p r fied f m hum r n

Action of growth hormone Wl n th growth l m e w fi t dt o er d t w s th ught that t p om ted th growtl f stems nd l a s nd in h b t d the growth of o t Thi wa d du ed f om e p im nts n wh h tle v r us plant p ts we e s ked in u n ol tio s Howe r later it wa fou d th t au n th pr m te r t hib t wth f a y g ve pl t g n som rg n b t g m r n t e than othe s Th s d ffe nt l en i t ty n b d scr bed th m how n th Ilu t at n R ot bud a d lea are ll hown t in r n g wth w th i a ng usin n tr t on but th pt mum f r ach o gan dif fe nt Thu n a x nc nt ation wl ch pro mot tl e g wth of t m an hib t th g wth of b d o ot By th s e cept th ame h rm ne y t m may t m l te om g th f nct ons n the plant d t h b t oth s at th m t m and en t the me pla e in the pl nt

I dd ti n t th ntr l o g owtl ex t d by th g owth l m the t maj r eff ts f the h rm o pla t Th h m pla a ba ic l the d ff ent at n f t s ue nd g n Fo e mple t pp r to pl y a majo l the d ffe e t ati n f xyl m—th w t p pe of the pl t Th t f ylem de elopme t h ve bee l ly l t d th th m u t f a m v ng th o gh t ms The xyl m d ff e t t imm d t ly xt t the pl l em ti e a d ambi m t s u wh h th p e p l a t s f a x n m ve m t n t n A th r maj effe t f the h m e pl t n l t eff t r eff ct n pla t f m S m f th h e alre dy be n men t ed i cl d ng th ff t lat l b d nhibi t l ch a gl nd g o th r t d r t g pattern

tion in Plants 1953 F W Went *Experimental Control of Plant Growth* 1957 P R White *Cultivation of Animal and Plant Cells* 1954

Plant hormones

Defined by F W Went and K V Thimann (1937) to be a substance which being produced in any one part of the plant is transferred to another part and there influences a specific physiological process Hormone can be described as chemical messenger They transmit the controls of pecific processes from one part of the organism to another They are usually pre ent in relatively mall quantities in contrast to ubstrates or mo t nutrients Plant hormones which control growth have been identified and hormones controlling flowering are suspected but not yet identified

With the agglomeration of large numbers of cells into organisms there must be ome organization of the cell ma or el e the result will be no more than a callu colony or tumor In green plants this organization can be thought of as a de elopment for the promotion of photosynthesis and the elaboration of ba ic food materials Such organization must entail a control of the sites of growth of the differentiation of cells into tissues and of the development of directi n or polarity in the whole mass Thus in a complex plant there must be regions of growth there must be tissues which serve the various needs of water supply food transport photosynthetic activitie mechanical support and the other functions of plant organisms and finally there must be a direction of the whole organism into a top and bottom or shoot and root The plant growth hormones are the principal chemical messengers that are known to carry on these physiological controls They are the developmental forces which direct so to speak the gro th and f rm of the plant

Nomenclature According to the van O e beek Committee (1954) the mo t generally accept d terms covering the plant gro th hormones and related natural and synthetic compounds include plant regulators the natural and synthetic organic compounds which in small amounts promote inhibit or otherwi e modify any physiological process in plants and plant hormones plant regulat rs which occur naturally in plants and usually move within the plant from a site of producti n to a ite of action

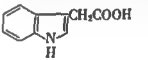
Two major di i ions of plant regulators are gro th regulator (comp und which affect growth) and flowering regulators (c mpound which affe t flowering) The ame di i ns apply to plant hormones thu there are plant growth hormone of which e eral are known and m y are yet to be identified and p ibly fl weri g hormones none of which are definitely identif ed a yet

The word auxin de ignate ne kind of growth regulator referring to that kind which ha the capacit for inducing elongation in ho t c ll i the manner f ind leacetic acid the be t kn wn pl nt gr wth hormone Included in thi ateg ry are synthetic plant growth regulators and the pl t growth hormones The best known ynthetic au in 2 4 D (2 4-dichlorophenoxyacetic acid) th weed killer

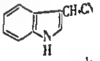
Known plant hormones From the abo e cla fication it will be di cerned that two types of h r mones are assumed to exist in plants growth h r mones and flowering hormones In additi n three other types of natural growth regulators are rec g nized the gibberellins which have enormou effect on cell elongation the kinins which have effect on cell division and finally growth inhibitors Each of these three types of factors has been detected in plants often in surpri ingly large amount f r such powerful biological agents and th ide t ties of ome of them have begun to emerg from the re earch of plant biochemists and phy i l t Whether or not the e materials are plant h rm nes in that they move from one part to another i till t be learned

Each of the two types of plant hormones ill first be discussed followed by a brief de cripti n of the three other types of natural growth regulat r

Occurrence of growth hormone The comm est plant growth hormone indoleaceti acid ha been found in many higher plants It wa fir t iso lated from plants by K V Thimann (1935) h found it in bread mold and it has ince been iden tified in corn oat bean sugar cane pineapple tomato and many other plants Until the 19 0 it was thought that this compound was the gro th hormone in all higher plants However increa ing evidence is accumulating which makes clear that many other compound are pre ent in plant h h can do the same job in stimulating growth O l a few of these have been identified includ ng i

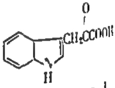


Indoleacetic acid



Indoleacetonitrile

Ethyl indoleacetate



Indolepyru ca i

d leacet nitrile ethyl ind leacetate and ind l pyru ic cid f rmulas f r the plant gr th h rm ne are repr duced here On chemi al g unds one can ee that each of the mi ht be e ily con erted i to indoleacetic acid and f ea h of the e comp und me id nce ha a crued that the c n er ion oc ur before the r lati n of growth i achieved H we er the q ti n i not mpletely an wered an l n m r other compound are yet t l e identif l me which give n chemical te t f r tl ind le a and hence l ul l l m il ing q it differ nt Ind lea tic c d i f m l f om tr pt pl a h ha l en ugg ted m m th t tl f

d e a chem c l r spo ble f r the g e t gr wth wh ch ha been p d and dent fied and named gibb r ll (e GIBBERELLIN) The are seve al l ly c l ted h c ls wh ch c r atu ally m pl nts nd fu g a d the e h e pr f und influ e ces the ormal gr wth and d l pment of pl nt Th y a e p ifi ally n olved n the bolt g h t g up f fl wer t lk f pl nt uch a p ch tob a d c bb ge a d they may be d ommer lly i a the b lt and flo n f ch t It i begn i to b l z d th t th g bbe ell n are i t m fely ol d th fl we in t mul s of th pe e lthough th y e n t pe fi ally th fl we ng h rm ne The g bb rell s ar ls ff tive n f ut set a d a e th ght to w k n o junct th the growth h rm e n th phys l gi l tep Th y a b t k wn th popular en f r the d m t eff t th y ha e wh n p ayed o to plants f r th y u e ery f rge n ea e pla t h ht F r mple appl t n t bb g pl nt will n t to gr w to a h ght f m e tha 10 ft Th g bb r ll s a l ble t b ak th d m cy of m y buds d eed

An th r k d f g wth gul tor wh h i n l d n th pla t ho m n sy t m r the ki th ell d n fa t S e al v tl t c hem l h be f u d wh h t m l te ll d vi o pl nt Ma y of the e a p es lated t ed n Se e l m t l h w g th s typ f a t ity h be n i l t d f m t e n wh h ab d t ell d n tak ng pla h th g m i g c uto l g ng y u g i t Th e hem l t n c ju tio w th the gr wth h rmo ult ng gr wth by ll d i t d f the al ll enl rgem t e p t the gr th h rmo N omme l ppl cat o s f th ki n f y t b e d l ped

Pla t g th h b t e i g c e s g t a g th lat r pla t d t g i t t w th th pl t g wth h rm ht gh it n t l r y t wl th r th m y be h rm n th m l M ny g owth i h bit r h s h n f nd pl t l d ng a l t m d p l t i phe ol ha hl g d dma i g d r m t d h al l a d (th s t l t f a p n) Th pl t g wth nh b t a po bl f r m ny typ f do m n plant d th a t a l t w n w th th o th l m d th g bbe ell n S AGRICUL TUR L SC CE (A T) A XI P T GROWTH T MET OLIS P T PHY O O Y [C L]

B bl g phy A C Le p ld A s d Pl t C wth 19 B S M te nd D B A l n Pl t Phy l g A ed 2 G P u d K V Th m (ed) Th H 1 3 1955 B B S d T Y m k Th h t y d phy l g l t f th g bb ll Am R Pl t Phy l 8 181 216, 19 H B T k y (d) Pl nt R g l t Ag lt 19 4 F We t V Th m Ph t h m 193

Plant keys

B ta i t h e u ed analyt cal keys in th id ntify i g of plant f r many year The ba i pr nc ple of such a key is the findi g of c ntr t ng chara te s a d the e of the e to sub d ide the gr up be i g st d d into two or m re bra l es For e am ple in a ollection of plants e has compou d l a es in co tr t t the the s ha g s mple l a es On this ba i th pla t are eparated and the o e w th ompound lea es i el m nated f om the range of po ib lities inhe ent in th th r plants th s th pr blem of ide tificat on is nar rowed The k y may tat that me plants are ha ry and s me gl brou that ome h ve yellow flowers and othe wh te By c f l e aminati n of th pl t by contra ti g e gh chara ter a d by el min ting enough membe s f the group the umber of p ib litie s fi ally reduc d t on the name of the plant b ing id nt fied If the plant be ng st d d d ffe n o e o m e l aracteristics fr m ll the known pla ts t i p sible that a new plant h been f nd

S ral d ff rent type of key h ve be n de sed A mu h u ed type th ind nted key in wh h the d cr pt on f each l act are inc as gly in d nted a g en d st ce fr m th l ft ha d marg f the pag The lin be om mo and mo in d nted as th key is extend d t incl de a larg r

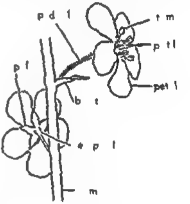


Fig 1 D g m of o mplet flow

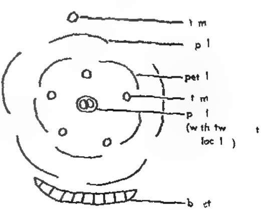
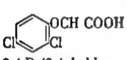
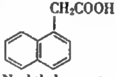


Fig 2 Fl l d g m f th fl w h w Fig 1

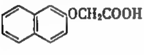
The mechanism of action of the growth hormone is an exciting area which is now receiving careful attention from plant biochemists. Several theories have been proposed to explain the action, but each has been made doubtful by further examination and experiment. Tests of various synthetic chemicals for auxin activity have permitted some generalizations about what the molecule must be like to be active in stimulating growth as an auxin. Almost all the compounds having this activity contain an aromatic nucleus and an acid side chain and a particular spatial configuration. Some synthetic compounds which are widely used as auxins include 2,4-D and related chlorinated acids, naphthaleneacetic acid, naphthoxyacetic acid, and 2,3,6-trichlorobenzoic acid. Formulas for some common synthetic auxins are given here. The manner in



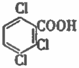
2,4-D (2,4-dichlorophenoxyacetic acid)



Naphthaleneacetic acid



Naphthoxyacetic acid



2,3,6-Trichlorobenzoic acid

which these various auxins can control the growth of plants is not clear, but the bulk of the evidence has at least established that the site of auxin is at the cell wall. In some manner the auxins cause a loosening and elasticizing of the cell wall, and through a stretching process cell growth then takes place with associated deposition of new cell wall material. The action is a metabolic one and results in marked stimulation of the metabolic rate as growth is increased.

Uses. Agriculturally the auxins have found numerous uses and have led to the beginnings of chemical control of crop growth. The largest use of the auxins has been in the area of herbicides. These chemicals cause death of plants at extremely low rates of application and also are highly selective. In general, they are more lethal against the broad-leaved plants than against the grasses, with the result that they are most useful in killing broad-leaved weeds in fields of small grains and corn. The most common auxin herbicides are 2,4-D, 2,4,5-T (2,4,5-trichlorophenoxyacetic acid), and the trichlorinated benzoic acids. In 1952, 60,000,000 lb of 2,4-D was produced in the United States alone. *See* HERBICIDE.

The actions of auxins on tissue differentiation permit three other agricultural uses: the rooting of cuttings, the control of fruit abscission or drop, and the induction of flowering. Rooting can be greatly stimulated in plant cuttings by dipping the basal ends into either a solution or a dry powder of auxin (*see* STEM CUTTINGS). Indolebutyric and naphthaleneacetic acids are the commonest auxins for this use. The premature drop of apples and some other fruits can be prevented by the application of auxins. Weak solutions of 2,4,5-trichlorophenoxypropionic acid are sprayed onto the trees several weeks before the fruit might start to drop, and the drop is not only alleviated but the color of the apple fruits is considerably increased. The initiation of flowering can be triggered in the pineapple with the application of naphthaleneacetic acid, a fact which has been highly useful in the commercial production of these fruits, simplifying the harvest schedules enormously. Few other species of plants have been found to share this flowering response to auxins.

One of the growth functions which the plant growth hormone controls is the complex process of fertilization and the commencement of fruit growth, or fruit set. When pollen germinates on a flower ovary, a surge of growth hormone production results, which starts the growth of the fruit from the ovary. In some species of plants the pollen can be substituted for by the application of synthetic auxins. This chemical setting of fruit, which results in a seedless fruit, has found commercial application in the culture of tomatoes and figs.

Flowering hormone. The seasonal flowering of many plants has been found to be controlled by the length of day in the varying season. From this discovery of photoperiodism it has been found that the stimulus to flower in response to day-length changes originates principally in the leaves of plants. Thus the stimulus must move from the leaves to the growing point where flower buds will be differentiated. This stimulus then can be considered as a flowering hormone, although it has never been separated from intact plants. *See* PHOTOPERIODISM IN PLANTS.

Various research workers have grafted together plants which have different day-length requirements for flowering and found that when a flowering plant is grafted to a nonflowering plant in various combinations, the flowering stimulus can move over to the nonflowering member of the pair and make it flower. It is deduced that the same flowering hormone is involved in the plants of the various photoperiodic classes. The stimulus can apparently cross between plants only when there is a living connection between them, and there has been essentially no success in extraction or diffusion of a flowering hormone out of plants. The flowering hormone is not the same as the growth hormone because it can move in any direction in living tissue and the growth hormone moves in a polar basal direction. *See* GRAFTING OF PLANTS.

Other growth regulators. One of the most dramatic discoveries in plant chemistry was that of the gibberellins. These compounds were isolated by Japanese scientists from rice plants infected with a disease which causes abnormally extensive growth. The fungus which causes the growth response, *Gibberella fujikuroi*, was found

n mb f ateg ri For n exampl of an in d ed k y se Tabl 1 A e ample of parall l k g en in T ble 2

I the pa allel k y two more c nt a t ng ch r s t ppe con ecuti e l es n the page o that th can be a ily comp ed

When conc rned w th relat ely m ll group n gen l, ndent d keys are g f able When c cerned w th l rg r groups p rallel k y are mo e t fact ry

T bl 1 Ex mpl f an ind ted key (g s C d m)

Lea es p t ly d ded	
b Le es ly ll b sal	*C hr l*
b t m l fy t th fl esc ce	
Lat l leafl t hl g pl ts	
f w t g d	
d Le fl t f l w l es	
ro d l d t lked pet ls	
l l em long	*C p t ns*
d Le fl ts th ba es d	
t l th his petal	
l 4 mm long	*C pe nsylva ca*
Lat ll fl ts l pl ts	
lly f dry gro l	*C l*
Le es t toothed t p	
t ly d d l	
b Flo rs p pl	*C d ugla*
b Flow rs b t	
t m t f m t berous	
b se	*C b lbos*
St m dec mbe t, t l f	*C rot nd f l*

T bl 2. Ex mpl f p rt on of p r ll l k y (cl ses a d f m l es)

1 Mos ly h ba eo pl ts w th l b dles sc t te ed hro h th p th Le es w th losed t mos ly pa ll l ed l t ed P t f fl w rs u lly 3 6s, ll hs cept th ge us *Sm lax* ( )	
1 ll t ero d woody pl t w th th l b d lly ed g bo t th p th Le es l ed th pe Fl w p ts us lly 4s or 5s (8)	
2 MONOCOTYLEDONS	
Flo ers th th t pe th th k fleshy pa f Le es pe led d t ed	Ara e
Flo rs th per th t bo pad (3)	
3 Per th pa ts dry d sc l l k b lly	
3 Peria th pa ts h ba eo col ed or h sc l l k l lly (4)	J cace
4 P th f ee from tl ry	Lil
4 P th more less db t t ry ( )	
Flo rs rr gul t m l ry drou	O h d e
Flow rs gul cept l t m 3 6 (6)	
6 Fl mpe fect pl t d oe cious l ml l ea t ed t	
6 Fl ers pe fect (7)	D osco
7 m 6 pe h p t mbricated the bu l	
tamens 3 peri h part co l t bu l	Am yll d ce
	I d ce

D grams symbols and formula may be n clud d in key The e m a e e are botanical shorthand in wh h many feat es of a plant may be repre ented n detail in limited pa e

Floral diagram The floral diagram s ntially a graph d ram of cro s section of a fl we (F 1) and may be represented as hown in Fig 2 It will be noted th t there are f (metime more or les) ets f fl ral pa ts a anged i who l n w thi a oth

Fl al symb ls The e may be u ed t r pr ent ious featu e of a flower Thus CA might repre nt th c ly (mp ed l sepals) CO the corolla (c mposed of petal) S th tamens and P th p t l (c mp d of carpels) Sm ll figu es written as e p ne t m y be u ed to indicate th number f p rts as CA Many other features c n be indi cated by add t nal symbols

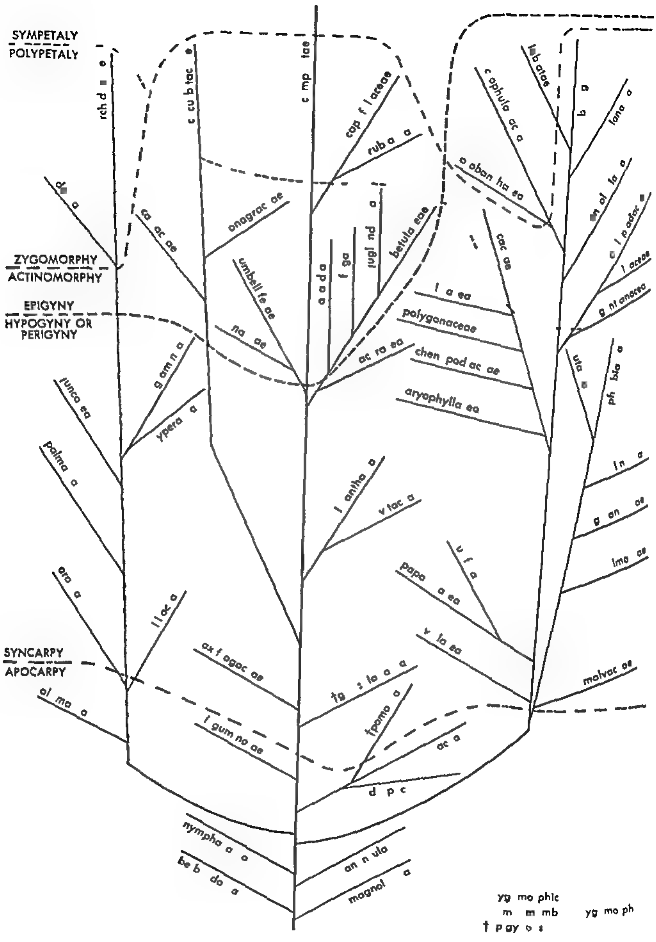
Flor l f mulas Combination f fl al symbol make p fl al formul Thus th tr tu e of flowe might b epre ented by the f llowing for m la

$$CA \quad CO^{3} \quad S \quad \underline{P^{3}}$$

Th s f mula g fie th t the alyx i mp ed of 3 epals the cor ll of 3 pet ls th t th re 6 t mens nd that the p til is m de up f 3 c r p ls nit d a dicat d by the circl bout the 3 Th l ne b n th th P ind te that th p stil s pe

Floral charts A floral chart may erve b th as a key t fam l e rd s a d g aph c repre sent t on f r l ti h p Wh n co c rned with el t vely mall g oup (hav ng f w f m lie) fl l ch t l ke k ys a ea er to m ke d t u Th floral ch t p t d i F g 3 arra ged e t ally co d g to th sy tem of Ch l E Be sey i n t mplete f th e t e Un t d State but it i l d m t f the la ge a d import nt fam l e nd ill t ates tf gen al n t f all s m la ha ts Th l ft bra ch prese t the m tyled s a d th te a d ght b a hes th d c tyled n The i r gul br ke er s l es h w that ert in mil r lut onary te d n e h o rred d ff r nt gr up of h gher pl t F e mpl all f m l e bel w a ert n li e ha e eg la r ll (a t n m phy) wh e s th e b th l ne h rr gul o lla (z gom rph y) All f m l e b l w another lin ha e c p l d st nct (t arpy) wh e s ll abo e t ha e th m n ted (yn arpy) By noti g that th lin s r s th r l b n he of th phyl g tc y t m t i e that th m ev lut ry ha g (i r l ty of fl w r n n f ca pel al ty) took pla e peatedl d ff t phyl g n t l nd t d ffe t tim a d t t d i d pe d t p o N te n th l we r ght c ne rd mp rt nt xc pt s but i l p c e h w g d t n f m the rule ccur many th r f m l S P A T CLASSI ICATION PLANT KI G OM [E L C]

B bl og phy S e PLANT TAXONOMY



Fg 3 Flo al cha t of most of the la ge a d impo a g d t ally acco d ng to th syst m f Cha l t t f m l es of a g osp m in the U ted Stat a E B ey

Plant metabolism

The e t compl of inte related h mi al eac t h r ct r t of l i g pla t on t t te pl t m tabol m. Kn wl dge of pla t metal ol m h gre d th gh the f ll w g tage (1) th hem c l de tificat on f the major c n t t f pla ts a d the e rly rec g it n of th p oce es f resp r ti and ph to ynth (2) th d e y f e zymes a d f the prom ne t e zym c taly ed reacti s and react on s qu nces a d (3) the p bl m f fi d ng tl fu ct on of th obser d pou d vme and re ct o a d the m an by h ch they a c tr ll d t provide th t d ly ng g er of e ent cha cte ist c of h g orga i m N e f thes stag s f d c ery is complet New pl t const t ents are r p rted e h y ar F r e ch n w compo d there t the probl m of dete min g ts mode of syn th a d the f ct on it serve Ea h nzymat c acti ty found in tract of ells n u t be related t th metabol m f th wh le rga ism The l borat n of o me n of metabol c trol mpha izes by co t t the nad g at ond rst d ing f others This fragme t ry knowl dge no thel s doe perm t the onst ct n f n o *derly* concept f met b l m

It c n ient t o s der that all the r acti ns in l ng cell f ll t thr e c tegori (1) tho e h h p o d ell tuff (2) tho e wh h pr id en gy nd (3) th e wh ch h ve o k own func *f* g een pla t the pro e f ph tosynth s *ppl* s f m carb n d ox de a d wate th mple mp d f m which fat a b hyd ates p o- n cle c d and othe ell ub ta c s re sy th zed (PHOTOSYNTHESIS) Nong n pl ts equ e a o t de u ce of ga s r b In b th a es th met bol c patt rn f th es the f ll tuff is th ame By m ny e en of ym t c lly t lyzed react n f act n f th mpl r o g c comp nd e ted to ll s b t n at the e pe f ergy pr du d h th o d ti n of the em d Be a gy q i ed f r th ynth f e h f th m jo n t t ts f l g ell imp t nt ph of th t dy of m t b li m is a de ti n of th p oe a d e t by wh h th en gy mad l ble Be a e th e n ed f n t f ev al cla f s b t ch fk l d t pe es t n d ntho ya n h h oc u *pl* t t mp bl to the ny m t b l f n t t the t wh l p du e th e c mp d *S* BIOLOG L OXI A ON *It* h l n t m ted th t th may be *ev r l* th d r t n r i g n l g ell E h f thes r t s taly ed by n fi nzym a p ot n m le ul th h ghly sp c fi tal t p pert U t l 1958 ly ab t 650 *n ym* m r ob th t t n t p ble t n truct a c mpl t p t f m t b l m A d ly n pi f met b l m p ll a a lt f th d o e (1) th t th *mpl* e gy

y lding degradation of metabol tes and the yn the es of new substa ce pr c ed by nt rdej end t e ie f rather mple chemical cha ge and (2) that the many enzym s c talyz ng the m ta b li rea ti are n t catte ed at random thro gh out th ll but a e or nted in the struct re of the cell a way th t f c lit tes their serial act on m t b lite mole ul s (se ENZYME PROTEIN) The met bolic f nctions a s ciated w th the tructures of a gre plant cell are l ted b low

Cell p rt	*Met bolic fu ct o s*
Chl ropla ts	Ph to ynthe i phot l y i of water ploto-nthet c ph ph ryl ation fixation of ca bon d oxide syn thesi of carbohy drates
Mitochondria	Oxidation of ar ous me tabolites transfer of lectron t oxyge ox dati e phosphoryl ation synthesis of proteins
N leus	Synthesis of nucle c ac ds synth sis of p o-te s
E dopla m c ret culum R bo ucleop t in p r t les	Sy the of pr tein ynthesi of nucleic ac ids

M ny p haps mo t of the eact ons ccurr g in pl nt cell also o cu n n mal lls a d bac te ial c ll Th re i a st ik ng u ty in the p oc by wh ch ar o ells obtain d util ze en e gy a d th p ce e by wh h the m j r cell s b tance e synthe i d Inde d much f th k owledg f pla t m tal ol m has lted *from* st d wh h imply nfirmed the ex t e f met b l c pathways l dy known f r an mal or m c gani m E en perf l c d rat n of d ff re t o gan m gg ts that the e m *s l o* b un que e n the met b li m of each organ m *S* CEL (BIOLOGICAL)

ENERGY METABOLISM

Wh te t th haracte isti a l fe c rt nly eq i n rgy Th main b sin f a ll *to* bt th gy d to use it i self m t n nce nd i lif-d pli at o A l ing ell ne gy n p f m g (1) h mical y *th se* (2) mot w k (3) mech n cal work (4) ele t i l work (5) l ght p d ct nd (6) heat pr d t f *the ll f h gh* pl nt m t of th rgy p d ed by th a r bi p ll d x d ti e ph ph ryl t This ce on i of mult ph e ymat tr n f f elect f m r duc d *fact* th o gh e f ytoch mes t ox g d th m t nt c n r t n f h m c l gy n a met r bl ph that c mp u d H i d d I h sphopyr d e ucl t d (DPN) d fla n d t e d leot de (FAD) (F 1) e a d n rs f lectr s to th cyto h me

Plant kingdom

The world wide array of plant life It includes plants that have roots in the oil that live on or within other plants and animals that float on or swim about in water and that are carried on dust particles in the air There is great variation in body form and size ranging from micro copic one celled organisms such as bacteria and certain algae to the giant redwood trees of California some of which exceed 300 ft in height and 30 ft in diameter and are over 3200 years of age Growth habits and life histories also differ greatly More than 350 000 living species of plants have been described New di coveries add hundreds of new species each year

This large number of forms necessitates some method of systematic plant classification so that plant scientists and others may handle effectively this great variety of organisms A fairly complete classification of the white oak for example would read as follows

Phylum Tracheophyta
Subphylum Pterop ida
Class Angiospermae
Subclass Dicotyledoneae
Order Fagales
Family Fa_aceae
Genus *Quercus*
Species *alba*

Scientific name *Quercus alba* common name white oak

A modern sy tem of cla ification of the entire plant kingdom is hown in outline form in the ac companying table

Articles on all the listed plant group appear under their pecific names *See* PLANT CLAS IFICA TION PALEOBOTANY [P D S]

Bibliography See PLANT TAXONOMY

Plant kingdom

Subk gd m Th ll phyta —Alg e
Phyl m Cya phyt —blue-g een algae
Phylum Euglen phyt —eugle ds
Phyl m Chl ophyt —green lg e
Phyl m Chry phyt —yell w g n algae gold n b wn lg e d d t ms
Phyl m Pyrrophyt —c ypt m d d di flag ll tes
Phyl m Pha phyt —b wn lg
Phyl m Rh d phyt — d lg
S bk ngd m Th ll phyt —F ng
Phyl m Scl omy ophyta—b ct a
Phyl m My omycophyta—sl m m lds
Phyl m E myc phyt —t u f
Subk gd m Emb y phyt
Phyl m B y phyt (Atracl t)—m ss pl ts
Cl s M —mos es
Cl H p t e—l wo ts
Cl ss Anth rot e—h nw ts
Phylum T cheophyt — ul pl nts
S bphyl m P l p d
Cl ss P l phyt
O d P l phyt lest
O d P l t l
S bphyl m Lycop d —cl b-m ss
Cl ss Lycopod
O l Lycopod l —cl b-mos
O d S l g ll les—sm ll l b-mosses
O d Lep iod l lest—g t l b-moss
O d Pl rom lest
O l Iso t les—q llw ts
S bphyl m Sph n l —h rs t l
Cl ss Eq t
O d Hy lest
O d Sph pl yll lest
O d Eq t les—h rset l
S bphylum Pt p da
Cl ss F l c e—f
O d Coe pte l l t
O l Oph glossales
O d M tt les
Ord Fl les
Cl ss Gym osperm e—co f rs d ll ed pl ts
S bcl ss Cyca l phyt
O d Cyc d fl c lest—seed f
O d B tt t lest
O l Cy d les—cyc l
S bcl s Co f rophyt
Ord Cord t lest
O d C kgo les—m d nh t ee
Ord Co f les—co f rs
O d C t les

Subphyl m Pt op d (Cont)
Cl ss A g o p m e—flowe i g pl ts
S bclass M cotyled n e
O d P d n l
O de H l b al
O d G m l
O d P lm les
O d Sy th les
O d A l
O d F les
O de L l les
Orde S t m les
O d O h d l s
S bcl ss D cotyl do eae
S bd o A h hlamyd e
O d C l
O d P p les
O d S l c les
O d My cales
O d B l n l les
O l Le t les
O d J gl d les
O l F g l
O l U t les
O l I t les
O l S t l les
O l A t loch les
O l P lyg les
O l C t pe m les
O l R les
O l P p les
O l S rra les
O l Rosales
O l C les
O l S p l les
O l Rl m les
O l M l les
O l I t l
O l Or t les
O l My t les
O l Umbell les
S l l Sympet l
O l I l
O l I m l les
O l Ebe les
O l C t les
O l T l fl les
O l Il t g les
O l R l les
O l Ca p l les

Q t t m rks l at t f l gr p m

f h w ly f m l t l

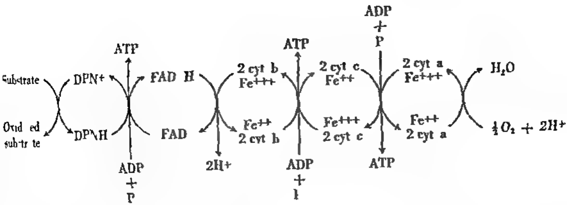


Fig 3 El ct t p rt d d r phosph ryl t

tem The ll compo ent s l ed th lec tr t fe y tem as well s th r qu ed f th m lt n ph ph ylat ar all l c l zed th m toch d f th ell The phosph ryl t n h h rs d electr n t n port t xy g th upt k f rg c pho phate nd th f rm t of n dd t l py opho pl at bo d (F g 2) d n s ed ph phat (ADP) to f m ad n triph ph t (ATP) The ch me f k wn t s le t n t p rt d d t e ph pl rylati t how F g 3

Th d ry f th mp t nt m f sy th f ATP f n fic n e l ecau ATP s the mmed t e f th hem cal e eq d t p f m th wo k fu t s l ted b Cle ge of e th f the pyr ph ph te b d ATP t the l se f ab t 8000 l/m l The zym t app m f l g cells all w th m t l e th bond n w y that make th e e gy a l bl f e e gy qu g ynthese and for the k d f k

Th prod t f edu d py d d fla t leot de l c n marily s the m t h d ly f d hyd ge at e ti s n h h th nzym fa t e ed c d d ng th dat f py d t rb d id nd t a d a d th fu th r x d t n f c t c ad t rbon d x d a d wat th ugh a y l c ser es t t th tr c d cy le (F g 4) Th fi t t p th f x d t t o th d t dec b xyl t f py at

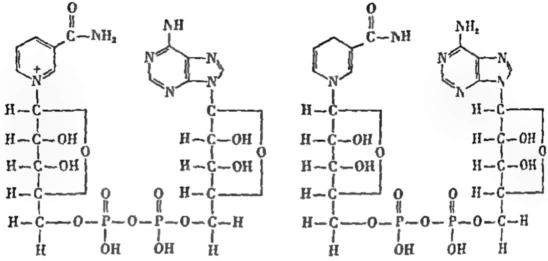
$$CH_3COCOOH + DPN^+ + CoA \rightarrow CH_3\overset{O}{\overset{\|}{C}}—CoA + DPNH + CO_2$$

t t m A (CoA) th d es w th t t t f rm t ate d f e n me A h h he ed ag th f rm t f n th m l l f l oe ym A f om py f Th d d f t (DPNH) d d t l f l t th gh th stoch m tem F m th t dp nt f e m t b l m th pn t l th t a d y l l ed p th f l f f ed d p d e u leo t le h h en t t ply th gy f f rm tio of aden etr ph ph t A m ll frac tion of the nergy req ired by plant cell is pro ded by a ae obi proce es d ed u der ca bohyd ates

Th met b li m of d ffe ent c ll ub tanc is nt r l ted nd interd pend t in many way F ex mpl the cof t r qu red by the itri ac d cy l n ym s a e l eq i ed in other o dati r du t r cti ns s ch a the sy the nd d g r dat n f fatty a d and f ca bohyd te Ther f th e an terdep ndenc f the action c taly d by these n yme In addit on p t u la comp d may be a termed t in the me t boli m f e eral d ff ent b tan e Acet te a tyl c en ym A pr d c d f m pyr at and f m th dat o of fatty ac d and in t n p e u r f f tty ac d c t rg n d a d i op en d omp d Furthe mo b e ade s t ph phate t th mmed ate re f e gy fo m t gy req i pr s e the rela t e ates f the p es will b f n t n f the le l f de t pho pl at The rate f p d ct on of ade o n t pho phat by d t e ph sph ylat s p tly f n t f th c n en t ti le el of ade os d ph ph t a d n g m ph ph te end pr du t n the util t on f den et iph ph te The e inter el t h p f the diff re t e ct n met b l m lth gh n mpletely de to d nd t t dly co t tut a y t m of t mat co t ol th t pe m t c llul r m t b li m t p d mo thly *See* ADENOSINE DIPHO PHATE (ADP) ADE O I ETRIPHOSPHATE (ATP) MET BOLIS I

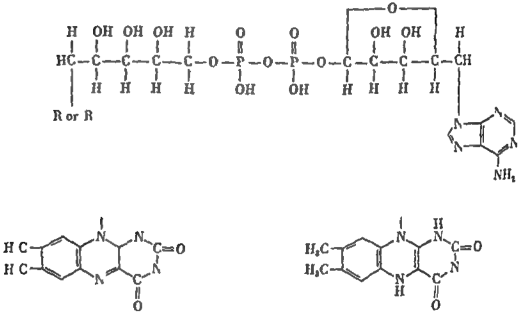
CARBOHYDRATE METABOLISM

The y the f ca b hyd at s fr m bon di id d w te by the p of ph t ynthe s ne f th mai f t e f c rb hyd ate me t b l m f g pl nt Th l hyd t th n pr ide th h kel to f ll the th ll b tances Alth gh ph ph ylat d d r ati e of gly e ald hyd ythr l l b e r b l f t a d d h ptul i h d n th cy li p f rb n di x d fi t n n ph t y the m h f th b n fi ed tr f med to fr t e gl c r d ta ch



DPN^{+} (oxidized f rm) DPNH (reduced fo m)

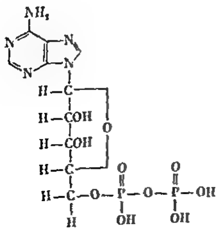
D pho phopyridine nucleotide



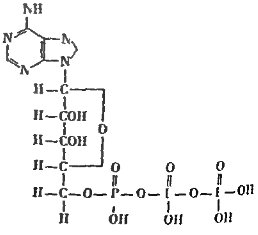
R = FAD (oxid ed form) R = FAD H (reduced fo m)

Fla in aden ne d nu leot d

Fig 1 Str ct al fo mulas of d ph phopy d ucleot de a d fla n aden ne d cleot d



Adenos nediph ph te



A leno t etr pl spl t

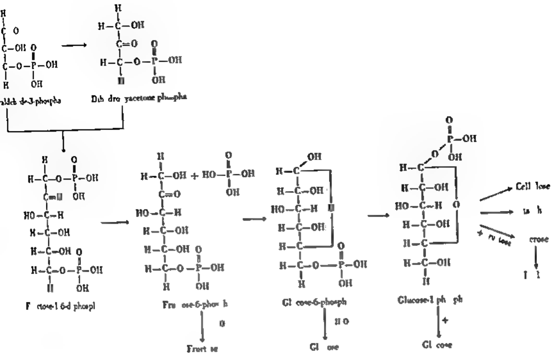


Fig 5 F m t f b hyd t f m gly ld hyde-3-ph ph t pl t

S g fi t q a tit e of gluc e m y be met b lized t f med by a ther t the p t e ph ph te p thway I th pathw y gl c e-6 ph ph te x d ed t 6-ph phogl nic d h h th n u d rg e d t dec b yl tio t f rm h l se 5 pho ph te Th f rther t fo m t of r b l e-5-ph ph t h wn n th d a gr m (F g 7) E zyme at lyzi g the t ans-f rm t h b en bt d f m pla t t e t ct E d c th t these e zymes fu t in p ded by th f ct that all f the m po d how h a rmal pl nt co t t t a d that C l beled i t rmed tes of th pe t ph phat y l a e quickly rt d t th e mpo d i l g t sues I y y g pl t t the Embd M y hof P p thw y p p a t be th ly pe t e m ha m f r th d m l ti f gluc I lde tissues the i m n r ng de l pm t f th p t m phos ph t p th y S CARBOHYDRATE METABOLISM

Starch Th m t b nda t eserve arb hy d t f the pl t ki gd m s fo m d sibly by th t f th e zym ta h pho ph ryl e on gl e-1 ph ph t

Gl e-1 ph ph t $\rightleftharpoons$ St r h + n Ph ph t

Th f rm t n of the l n p lyme of ta h myl se requ th pho pho yl se e zyme wh ch is pec fic f th f rm t of α 1 4-glyc id l k ges (F g 8) Th b hed polyme myl p t i f rmed by th ct m f bra h g zyme (Q zym) wh h tra sf h t h of th l polym t th 6-hyd xyl p t f th gl cosyl res d es f myl e (myl pe t) h n. In dd t n t be g d gr ded by t ch ly

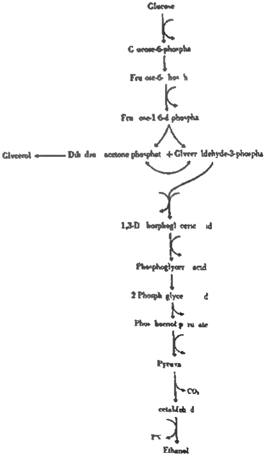


Fig 6 Th p thw y f gl d m l t gly ly

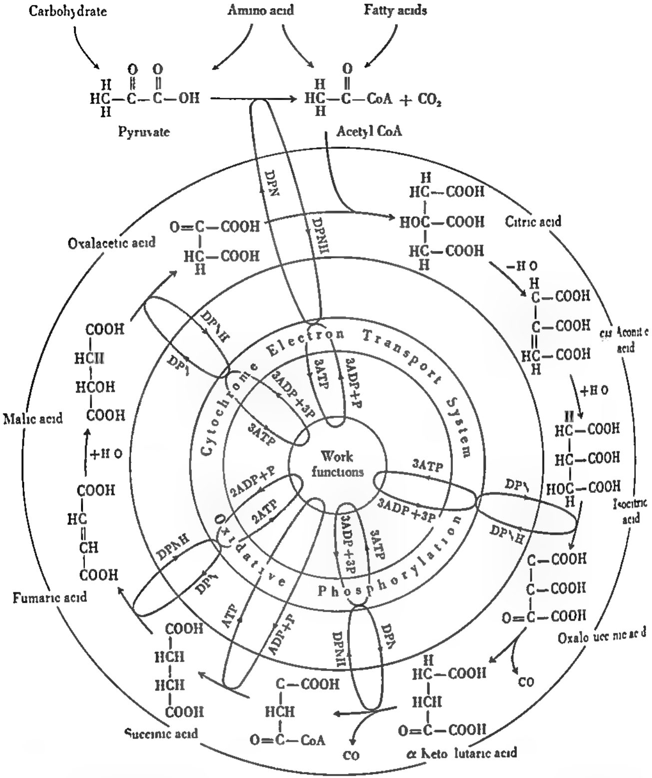


Fig 4 Citric acid cycle

These carbohydrates then undergo further metabolism independent of the process of photosynthesis.

The glyceraldehyde 3 phosphate produced in the photosynthetic cycle gives rise to other carbohydrates as shown in the reactions in Fig 5.

When glucose (from photosynthesis or from hydrolysis of the storage carbohydrate starch and sucrose) and fructose (from sucrose or inulin) are degraded to obtain energy or to provide carbon skeleton for the synthesis of other compounds the initial reaction is one of a series of phosphorylated intermediates. This pathway of dissimilation (Fig 6) is referred to as glycolysis or the Embden Meyerhof Parnas pathway. Under anaerobic conditions appreciable quantities of ethanol accumulate and there is a net production of only 2 moles of ATP for each mole of glucose converted to ethanol and carbon dioxide. Although many microorganisms can obtain sufficient energy by anaerobic processes to maintain their life cycles higher plants cannot. Under aerobic conditions the DPNH produced by the oxidation of phosphoglyceraldehyde to phosphoglyceric acid is reoxidized by the cytochrome system and ethanol is not formed.

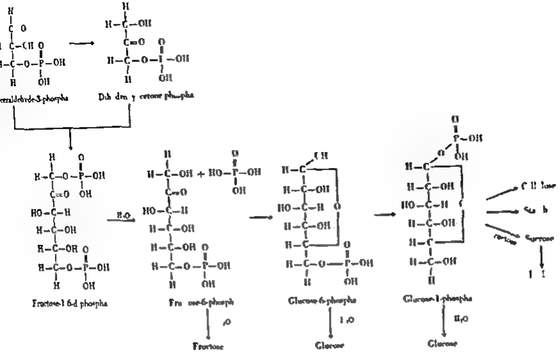


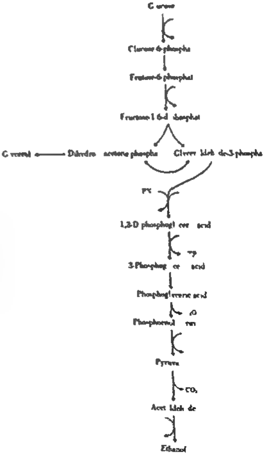
Fig 5 F m to f bohyd t f m gly ld hyde-3-ph ph t l pl ts.

S gn fi t q antitie f gluc may be m t bo- lized o t f rmed bv ther te the p t ph phat p thway In th p thway glu e-6- pho ph te dized t 6-phosph glu ic id b h th n nd g e d t e dec rbo ylati to f rm rib l e-5-ph phat The fu th t lo ma ti f b lo e-5-ph ph t a e sh wn in the d gram (Fig 7) E zym cat lyzi g th e tra s- f rm t h e bee obta ed f m pla t t tr ts. E d th t these nzymes fu t in vi p o ded by th f t th t all f th c m po d sh w he rm l pl t stit ts nd th t C[1] l b led inte med ate f the pe t phosph t cy le e qui kly co t d i to ther mpo d l g t In ry y u g pl t ti th Embd Meyerh f P rna p thw y ap- p s t b th ly pe ti e m ch m f the d imil t n f gl c s I ld t e the e i sn e g de l pment f the pe to e ph s phat p thw y S CARBOHYDRATE METABOLISM

Starch Th mo t bundant rve arbohy d te f th pl t k ngd m s f med r e blv by th t f th zym sta ch ph ph ryl on l ph ph te

n Gl e-l ph ph t $\rightleftharpoons$ Sta h + Pho ph t

Th f rm t f th l e polym f ta ch myl e r q th ph pho yl s nzym whi h is pec fi fo th f rm ti f l 4-gly d l nk (F g 8) The b h d polym amyl pect f rmed by th act f b an h g e zyme (Q ym) wh h t fers h rt ch f th h p lym to the 6-hyd xyl p ti n f th glyc yl r d f an myl s (amyl p t) h in In dd ti t b g d g ded by t ly s.



Fg 6 Th e thw y f gl d m l t gly ly s.

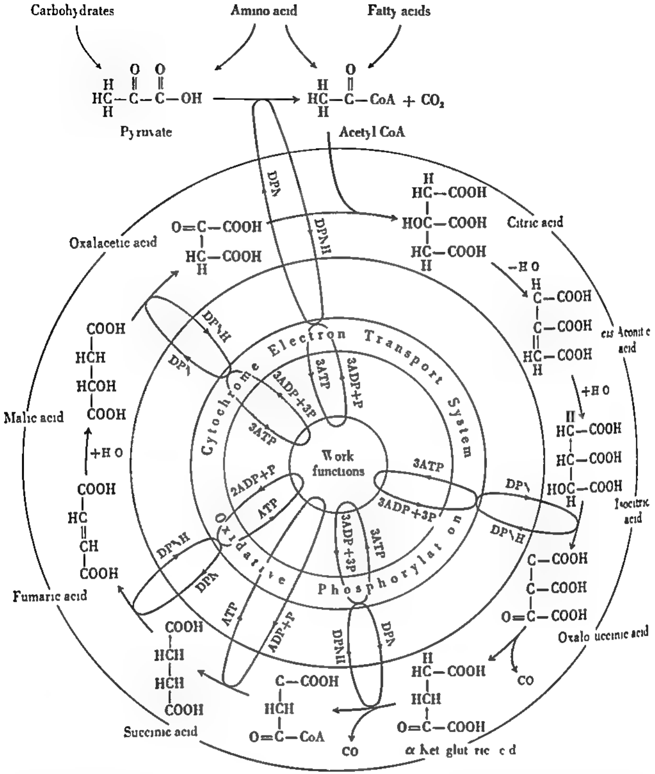
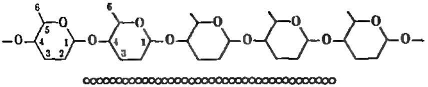


Fig 4 Citric acid cycle

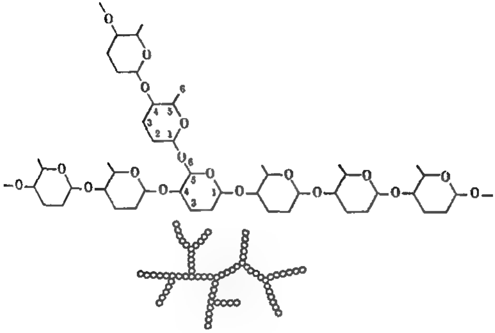
These carbohydrates then undergo further metabolism independent of the process of photosynthesis.

The glyceraldehyde 3-phosphate produced in the photosynthetic cycle gives rise to other carbohydrates as shown in the reactions in Fig 5.

When glucose (from photosynthesis or from hydrolysis of the storage carbohydrates starch and sucrose) and fructose (from sucrose or inulin) are degraded to obtain energy or to provide carbon skeleton for the synthesis of other compounds the initial reaction involves a series of phosphorylated intermediate. This pathway of dissimilation (Fig 6) is referred to as glycolysis or the Embden Meyerhof Parnas pathway. Under anaerobic conditions appreciable quantities of ethanol accumulate and there is a net production of only [illegible] mol of ATP for each mole of glucose converted to ethanol and carbon dioxide. Although many microorganisms can obtain sufficient energy by anaerobic processes to maintain their life cycle, higher plants cannot. Under aerobic conditions the DPNH produced by the oxidation of phosphoglyceraldehyde to phosphoglyceric acid is reoxidized by the cytochrome system and ethanol is not formed.



Amylose



Amylopect

Fig 8 L d b h d p lym f ı h

p bl f th ap d decay a d l b l zat
of d d pl t r d S CELLULOSE

Pectin The g l ct ı d r dues f the pe t mp u d appe t ar e d tly fr m the gl kel t by x d t f carb at m 6 d ı e s f th o fig rat f ca b n t m 4 The m thyl est g p om f m m thı by t m thyl t E zymes b ng g ab t the d g d t f p t e mp d a f t kt d O pe t m thyl e t e the hyd ly f th e te l kages t y eld p t d nd m th l Th th pect d p lyme e l e the p lym r to g l t d nd d g l t n d Thes zyme ur wid ly ı plant t ue d n m gan m (see MICRO BIOLOGY) N t w thy the mp t th p g f f he th h t st e p gr s- lec firmn th r lt of deg d t f th p t omp nd th ll t ct S FRUIT (B TANY) P IN

Ascorbic acid Th b t c lo ly r l t d t the b hyd te d f n ly u e s l c rre pl t b t y t has l arly t b l d f t It ynthe a h wn F g 9 S ASCORB C ACID

ORGANIC ACIDS

By irtu f th wide d str b tion ın relatively l rg qua t t e th pl nt kingdom e eral l ph tic a d ar efe d t coll tı ely the pl nt id Thes clud the ıd ın the f rm of a d est for ample m late c trate ı cı t te t trat suc t x l t f mar te a n tat l tat α k togl t a d glyco- l t The g c ds d the r salts tıt te b ffe ıng yst ms wh h und bt dly ar of ım p t nce ın ntr ll ng the pH (c d ty) f the ll O g cıd n tral e th eff ct f n x pt ke of cat o F xampl wh po- t m n t te t ke up by a pl t a d the n t te r d d to mmo um th s n ex es of at n ın th ll Th s b la c d by th ynth ı f o c d a o Th s th o ga ıc d c te t f a pl t g wn nitrate s s u ce f n t og n I t m s that of a plant g own w th mm ı m alt a ce of n t gen

Functions of organic acids S e l f the pla d cc ı te m d t th dati n of etyl c e zyme A by th c trı ıd cycle B c u m y k nd f o g n ms op te th t c ac d

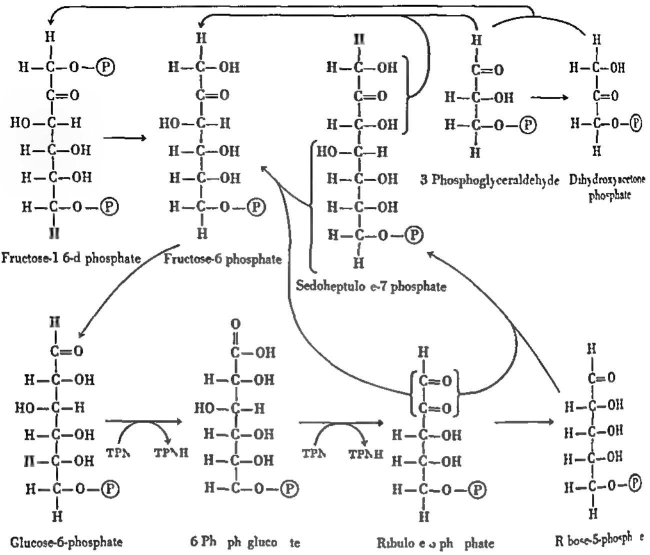


Fig 7 Pentose phosphate pathway

phosphorylase starch is hydrolyzed to maltose by the combined action of α and β amylases The α amylases are specific for the hydrolysis of the 1 4-glycosidic linkages in the interior portions of the starch molecules and consequently rapidly lower the viscosity of a starch suspension producing dextrins as end products The β amylase attacks starch molecules at the nonreducing ends cleaving off maltose units one at a time In seeds which contain a high percentage of starch there is a severalfold increase in amylase activities during germination *See* STARCH

Sucrose In higher plants sucrose synthesis occurs by the following reactions

Uridinediphosphoglucose + Fructose $\rightleftharpoons$ Sucrose + Uridinediphosphate

Uridinediphosphoglucose + Fructose-1 phosphate $\rightleftharpoons$ Sucrose 1 phosphate + Uridinediphosphate

Sucrose 1 phosphate $\rightarrow$ Sucrose + Phosphate

Uridinediphosphoglucose is formed by the following reaction

Uridinediphosphate + Adenosinetriphosphate $\rightleftharpoons$ Uridinetriphosphate + Adenosinediphosphate

Uridinetriphosphate + Glucose 1 phosphate $\rightleftharpoons$ Uridinediphosphoglucose + Pyrophosphate

The conversion of sucrose to glucose and fructose is by a hydrolytic cleavage catalyzed by the enzyme sucrase *See* SUCROSE

Pentoses and pentosans Ribulose-5-phosphate and xylulose-5-phosphate occur as intermediates in the photosynthetic cycle whereas ribulose-5 phosphate and ribose 5 phosphate are intermediate in the pentose phosphate cycle Ribose and xylulose can arise by the hydrolysis of their phosphate esters Xylulose is isomerized to xylose which further transform into arabinose through the intermediate formation of uridine diphosphoxylose and uridine diphosphoarabinose However there is no evidence that these free pentoses can serve as precursors for the formation of pentosans Isotope labeling experiments indicate that the pentose residues of pentosans arise from hexoses by loss of carbon atom 6 *See* CARBOHYDRATE

Cellulose It appears that cellulose is synthesized by one or both of the following reactions

Uridinediphosphoglucose + $(\text{Glucose})_n$ $\rightleftharpoons$ $(\text{Glucose})_{n+1}$ + Uridinediphosphate

n Glucose 1 phosphate $\rightleftharpoons$ Cellulose + n Phosphate

Enzymes that hydrolyze cellulose known as cellulases occur primarily in microorganisms and are

ac d and carbohydrates the foll wing details of acid metabol m of s cculent are established Mal te is formed by a carboxylation react on

Pho phoen lpy u ate + CO_2 →
L Malate + Phosphate

and ı th chief part cipant ın the d urnal fluctua tion of acid content The phosphoenolpyruvate arıse pr ma ly from ca bohydrates In the light m late con erted by way of the hexo es into tarch In the dark starch ıs ı n erted by way of th h o es (and pento es) to phosphoenolpyru te wh h ıs then ca boxylated by carbon dı xide p d ced ın respı at on Cıt ate participates to som extent n the diurnal fl ct ation of acidity It m y be f rmed by a c rboxylation reaction

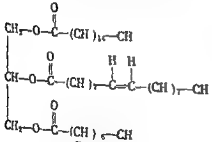
α-Ket glutarate + CO + TPNH →
TPN + Is citrate
Isoc trate ⇌ Citrat

by the e r on of m lat to ıt t

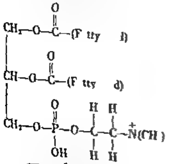
Alth gh o t c a id a m jor co st tuent of m lent pl ts ıt s ot ubject to d u nal arı n n e n t at n It a umul tes l wly ın the le es nd afte the ddıt n f C labeled car bon d x de ın th r l ght or da k bec m l beled ery sl wly n tra t to malate nd cıt ate

LIPID METABOLISM

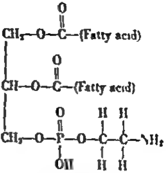
Th l p d ı lude a group of ul tan e that y ld fatty a ids hyd lys s These are the fat d l (tr glyce de) ın which the fatty acid a este ified w th gly r l the wax s ın wh ch th f tty d a e este fied w th l ng-cha n mo o-hydrı lcohol nd the ph sph l p d n wh ch th f tty d re este fi d with gly er l o w th the l h l w th wh h ph sph d nd b ı nı ı o s co titu nts are mb d



T gly erid



Lec th n



Cephalin

Lıp ds

The co tituent fatty acids of th lipid may be saturated or n atu ated and may c ntaı 4-26 carb n atom With few exception tl e a ıds are u branched and c nt ın an e en number f carl n at m Th le f fats c taı linolenı lı l ı and ole c acid a prı cipal fatty acids Fruit fat ch a p lm a ocado and ol e co taın prı ı pally palmıt and le c a d wher a tl ere a great rı tı ın the f tty a d ompo tı n f ed fat The tru tu e f the t ıglyce ıde that ha been ch racterı ed ugg t tl at there c m plete a domızatı ın the format n of triglycer ıde fr m fatty acid a d gly r l th t ı f ı d oil on st f m xtures of mixed triglyc rides ath th n of mı t re of pure triglyce des

Th fatty a ds re y thesized by the onden a t n f ac tate units (ac tyl CoA) f ll wed by re d tı n T glyc rides are form d b th c nd n t n f tw mole ule f f tty a d a yl c e zym A with α glyce pho ph te d ph phorylatı n of the ph sphat dı acid f rmed followed by th c d n at n f a f tty a d a yl CoA with the digly erid Le thın a e form d by th t an f f the phos-ph ylcholı e m iety fr m cyt d ne diph phocho-l e t d gly eride Cephal s a e f rmed l y an alogo e t on tıl z g yt d ne diph pl o-than l min

Th d gradatı n f t ıglycer d o e by way f a l pas ataly d hyd olysis t glyce ol and f tty c d The fatty ds a e con e t d t cet l C A s shown n F g 10

Th e a e tw pe od ın the life cycle f cert ın h gh pla t whe fat met b l m dom ate ther b h m l e e t In the o l b a ı g specie the e s b f p od du g the format n f th eed n wh ch th ıl t nt f the s d c es ten t thirtyfold Du ı g thı pe od th re p r t ry qu t ent f the ed ın rea es to val ı h gh as 1 5 d c tı g that th tr gly de synthe oc s n th eed t lf f m m h gl ly o ıd ed s b t at h a ca bohydrate Du g the germ n tı n f o l b g d the e ıs a rap d on f t glyc r de t c b hyd t s wh h are th n tr l at d t the gr wing po t o s f the se dl ng Th c e sı m n f t by l w re p atory q t nt (d wn to 0 3) In germ at g d th apid met b l m f f t s a mpa ıed by th synthe ıs f zyme that a e requ d f r th ap d metal l m Se LIPID METABOLIS

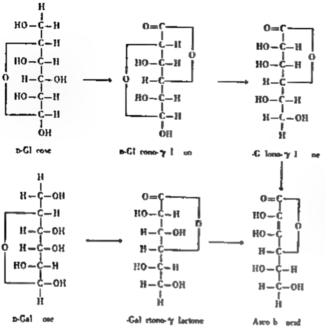


Fig 9 Bo ynthesis of ascorb c acid

cycle without the accumulation of large quantities of the intermediates it must be concluded that the accumulations that do occur such as malate in apples and citrate in tomatoes are incidental to the operation of the oxidative cycle These accumu lations may result from a block at one point in the cycle or from excessive cations pre ent All the acids listed above with the exception of oxalate and tartrate are in dynamic equilibrium with other plant constituents that is the pools of accumu lated acids are undergoing metabolic turnover For example a single administration of C labeled glucose to a tomato results in a rapid labeling of the citric acid without any net increase in the total citrate present Then with time the label disappears from the citrate with no decrease in total citrate pre ent

Some of the organic acids which are intermedi ates in the citric acid cycle are also synthesized in significant quantities by other pathways Malate synthesis occurs by the following reaction in which P_i repre ents inorganic orthophosphate

$$\text{Pyruvate} + CO_2 + \text{DPNH} \rightleftharpoons \text{Malate} + \text{DPN}$$
$$\text{Phosphoenolpyruvate} + CO \rightarrow \text{Oxalacetate} + P$$
$$\text{Oxalacetate} + \text{DPNH} \rightleftharpoons \text{Malate} + \text{DPN}$$

I ocitrate can be formed by a re er al of the isocitric dehydrogenase reaction

$$\alpha\ \text{Ketoglutarate} + CO_2 + \text{TPNH} \rightleftharpoons \text{I ocitrate} + \text{TPN}$$

I ocitrate can then give e *cis* aconitate and citrate

Oxalacetate and α ketoglutarate can be produced by the deamination of the amino acids aspartic acid and glutamic acid respecti ely

Tartaric acid and its alts accumulate in large quantities in grapes and are found in smaller quan tities in the leaves of many plant specie The rate of synthesis and accumulation of tartrates is slow and further metabolism is extremely slow The im mediate precursors of tartaric acid are not known

It is clear however that the clo ely related malic acid is not a precur or Oxalate alts also accumu late in large quantities in ome plants through oxidation of glyoxalate Oxalate is metabolized fur ther to carbon dioxide formate or both at a very slow rate by most plant cell The table gives an incomplete but repre entative li ting of the occur rence of various organic acids in plants.

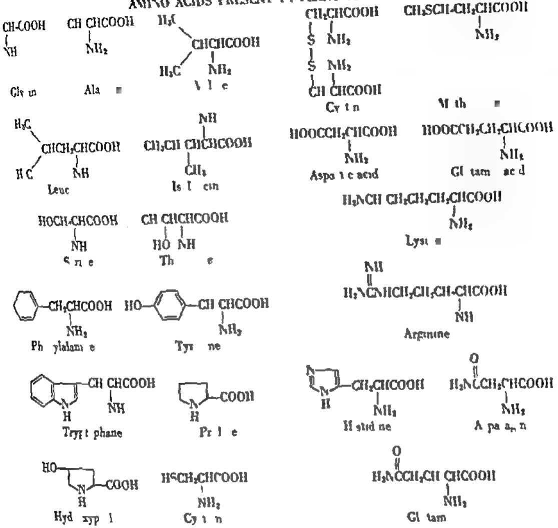
Acid metabolism of the succulents In some species of plants there is not imply a low ac cumulation of organic acids but rather a large diurnal fluctuation in the total acid pre ent These fluctuations are characteristic of a group of plant known as succulents which are characterized b thickened spongy leaves and tems Typical uc culents occur in the families Cactaceae Begonia ceae Compo itae and Cra sulaceae the genera *Bryophyllum* and *Sedum* of the Cra sulaceae ha e been most extensively studied The main features of the acid metabolism of succulents are (1) a rapid increase (one- to fivefold) in total acid ty at night and an equally rapid decrease in daylight (2) increase in the rate of acid formation brought about by low temperatures (3) ame inten ity of light required to bring about a decrea e in total acids as that required for photo ynthe is (4) a very low respiratory quotient (CO evol ed/O- ab orbed) less than 0 1 during the fir t hours of darkness and (5) a concomitant disappearance of carbohydrates particularly starch as the acids ap pear The low and sometimes negative respiratory quotient values sugge ted to early experimenters that carbon dioxide was a reactant in the formation of the acids (*see* PLANT RESPIRATION) Two kind of evidence confirm this suggestion Fir t the rate of acidification of succulent leaves in the dark is a function of the carbon dioxide concentration over the range 0–1% Second C labeled carbon di oxide i incorporated immediately and principally into the malic acid formed By virtue of the earl er experiments in which the concentration of acid and carbohydrates was measured and of the later experiments with C labeled carl on dioxide

Organic acid content f va ious plant tissues

T s	C t	M l	I o- i	O l c	T t n	Suc ci
L f (meq/100 g dry leaf)						
Rh ba l	31			143		0 5
B y phyll m	4	166	13	[illegible]		4
A col						
t ba um	3	68		3		0 06
T m t	4	[illegible]		45		
Sp h	10	9		309		
V l g	7	68		8		
F u t (meq/100 ml j ice)						
V l g						
Imm t	[illegible]					
M t		6				
Lemo						
Imm t	3	4 4				
M t	106	9				
Appl j ce	3 1	0 3				

meq = m ll eq l t

AMINO ACIDS PRESENT IN PLANT PROTEINS



t the form of ammonia nitrogen. The path y i red ct on f tr t th gh a e f tw el tr t sf s

$NO_3^- \rightarrow NO_2^- \rightarrow NOH \rightarrow H_2N{-}OH \rightarrow NH_3$

Nitrate Nitrite Ni Hydroxylamine Ammonia

Nitrate reductase, the enzyme catalyzing the first step, has been d from A o p a d f m th ue f ma y h gh plants. It a molybdo-flavoprotein which transfers electrons from TPNH t nitrate

$NO_3^- + TPNH + H^+ \rightarrow NO_2^- + TPN^+ + H_2O$

Th d s ry th t th zym ju m lybd t i t to pr d b h m le pl n t n f th q i me t f pl t fo m lybd t Alth gh n i t ed ct d hyd o yl m r d ta t e h b n b erved pla t tra t th e zym q f nh ha t za t n w th r p t t zym d m t l qu m ts

Significant quantities of nitrogen from the are r d ed t ammo a by free-living bacter the soil d by th *Rhizobia* which grow i ymb with the leguminous plants. See Lec II te. SOIL MICROBIOLOGY

Ammonia is n orated into the ga c n t o- ge mp d f pl t th ugh th m at f α-ketoglutarate and pyruvate to form glutamic and aspartic acid and alanine, r p c u ly. Experiments with N labeled ammonia ha e h wn th t th mi o c d d prot f pl ts nderg nst t br kd w a d re y the In su h p m ts glutamate and p tat th f st mi e d t be m l beled with N Th p i p l t n f nco p t g m mo a to amino groups appe b th t ta ly d by glutamic dehydrogenase

Th m d f med by d t m t f α-k t d n t sf their amino groups by t m t r t nst th α-keto acid fo m th p nd ng amino acid. Th r a m ny d ff e t tr mi en ym ll f which q i pyridoxal phosphate a o yme P o-

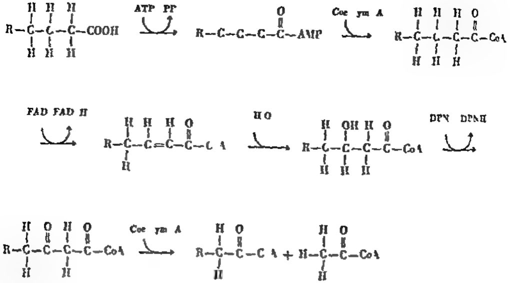


Fig. 10 β oxidation of fatty acids

PRINCIPAL FATTY ACIDS OF PLANTS

Acid	*Formula*
Lauric	$CH_3-(CH_2)_{10}-COOH$
Myristic	$CH_3-(CH_2)_{12}-COOH$
Palmitic	$CH_3-(CH_2)_{14}-COOH$
Stearic	$CH_3-(CH_2)_{16}-COOH$
Arachidic	$CH_3-(CH_2)_{18}-COOH$
Palmitoleic	$CH_3-(CH_2)_5-\overset{H}{C}=\overset{H}{C}-(CH_2)_7-COOH$
Oleic	$CH_3-(CH_2)_7-\overset{H}{C}=\overset{H}{C}-(CH_2)_7-COOH$
Linoleic	$CH_3-(CH_2)_4-\overset{H}{C}=\overset{H}{C}-CH_2-\overset{H}{C}=\overset{H}{C}-(CH_2)_7-COOH$
Linolenic	$CH_3-CH_2-\overset{H}{C}=\overset{H}{C}-CH_2-\overset{H}{C}=\overset{H}{C}-CH_2-\overset{H}{C}=\overset{H}{C}-(CH_2)_7-COOH$
Ricinoleic	$CH_3-(CH_2)_5-\underset{H}{\overset{OH}{C}}-CH_2-\overset{H}{C}=\overset{H}{C}-(CH_2)_7-COOH$

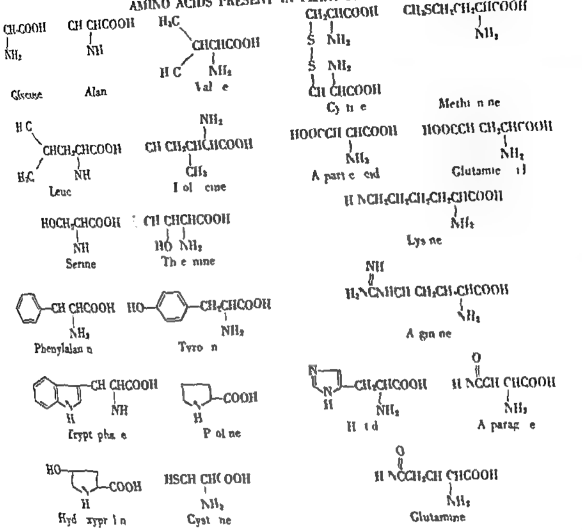
NITROGEN METABOLISM

Amino acids, amides, and proteins. The principal nitrogenous constituents of plants are proteins. Although there are many kinds of protein in plants, they, like all proteins, are made up of a relatively small number of different kinds of amino acids condensed together through the elimination of a molecule of water between the carboxyl group of one amino acid and the amino group of another. With two exceptions, proline and hydroxyproline, all of the amino acids which have been obtained from protein hydrolyzates are α-amino acids. The α carbon atom is a center of asymmetry, so that two *optically active* isomeric forms are possible for each amino acid. Only the L-amino acids have been found in protein molecules. In addition to the protein amino acids, many other amino acids occur free or in simple organic compounds. Although some D-amino acids are known in biological material, the different kinds and quantities are much more limited than for the L-amino acids.

The carbon, hydrogen, and oxygen for the formation of amino acids in plants come from carbon dioxide and water by way of photosynthesis.

Soil nitrate is the principal source of nitrogen for higher plants (*see* NITROGEN CYCLE). The occurrence of nitrate in soil is the result of the microbial nitrification of the ammonia produced by the degradation of plant and animal residues. Nitrate is absorbed into the roots of plants and in most species is translocated as such to the aerial portions of the plant, where it is reduced to ammonia. Root cells also are capable of reducing nitrate to ammonia and in some plants a major fraction of the nitrogen transported out of the

AMINO ACIDS PRESENT IN PLANT PROTEINS



t r th f rm f ami n trog n The p th w y f red cti n f trate th gh se i of l o el ctr t n f r

$$NO \rightarrow NO \rightarrow NOH \rightarrow H_2N{-}OH \rightarrow NH$$

Ntr t N t t Ni Hydr Ammo a t xyl ylam

N t te red ta th zym at lyzi g the fir t t p h s b obt ed f om *Ne* n nd f om th u u f m ny h gh pl t It s m l bdo- fla p t n wh h t nsfer l tr s fr m TPNH t t

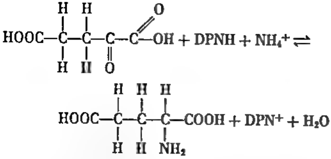
$$NO + TPNH + H \rightarrow NO^- + TPN^+ + H\ O$$

Th d ry that th nzym q i e m lybd te an n t at p de a b h m cal pla n u f r th qu em nt f plant f r m lybdat Altho gh tr t ed t a d l yd yl m e e du ta t t b b erved pl t xtra ts th e zymes qu f r the ha act iza ti with r pe t t zym a d m t l n q m nts.

S gnifi t q ant t es f n t gen g fr m th a r are ed ced to mm a by free-li g bacteri i th so l a d by the *Rh zob* which g w ymbi a with th legum u pl nt S LEGUME SOIL MICROBIOLOGY

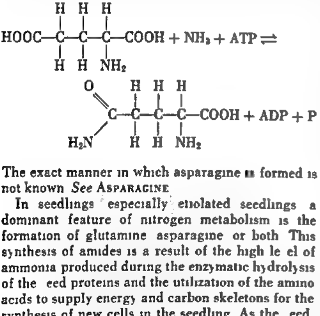
Amm ni i rp r ted into the gan tro- g mp nd f plant th ugh the ami i n f α ket gl t rate x lac t t d pyru te t f rm gl tam cid partı c d a d alanine re pec ti ly E p r ment w th N labeled mm ia h h wn that the am no a ds and prote ns f pl nt u d rgo c n t nt b e kdo n a d re y the- I s h experim nt glutam te a d p rtat a the fi t m n a ids t bec m l bel d w th N The p n ıpal react n f i co po ati g m m n nt m g up pp r t b th t c t ly ed by gl tam d hyd g n

Th m n a d f med by d t m to f α keto ac ds t n f the m g o p by t n m at n e n t th α ket d t f rm the c r po d g m d Th e a m y diff nt t am n eym ll of wh h r q e py d l ph ph t s nzym P



line and hydroxyproline cannot be formed by transamination reactions. Proline is formed from glutamic acid by way of glutamic acid semialdehyde and pyrroline carboxylic acid. Hydroxyproline is formed by oxidation of proline. Higher plants are able to synthesize all the amino acids which they utilize in their metabolism. Some of the lower plants and some bacteria are not able to synthesize all the amino acids which they require and are therefore dependent upon plant and animal residues to supply them preformed.

Although ammonia is an intermediate in the metabolism of living cells, ammonium salts are extremely toxic if allowed to accumulate in the cell. Living organisms prevent the accumulation of ammonia by excreting it or by combining it into some innocuous compound. Higher plants incorporate ammonia into the amides glutamine and asparagine. Glutamine is synthesized by the following reaction



The exact manner in which asparagine is formed is not known. See ASPARAGINE.

In seedlings, especially etiolated seedlings, a dominant feature of nitrogen metabolism is the formation of glutamine, asparagine, or both. This synthesis of amides is a result of the high level of ammonia produced during the enzymatic hydrolysis of the seed proteins and the utilization of the amino acids to supply energy and carbon skeletons for the synthesis of new cells in the seedling. As the seedlings develop and the level of ammonia drops, the amides gradually disappear as their nitrogen is utilized in the synthesis of other amino acids to be used in protein synthesis.

The prominent feature of the nitrogen metabolism of any growing cell is the synthesis of the cellular proteins. Because there may be as many as several thousand different kinds of proteins in a cell, it is obvious that protein synthesis in a rapidly growing cell is a result of very complex processes. Proteins may differ from one another in amino acid composition, in amino acid sequence, and in the three dimensional folding of the long polypeptide chains. These characteristics are of course under genetic control (see GENETICS). Some of the most interesting developments in biology in this century center around the discovery that the genetic material of cells consists of nucleic acids and of nucleoproteins and that the biosynthesis of proteins and nucleic acids is interdependent and simultaneous.

Proteins appear to be synthesized directly from amino acids by an energy dependent (ATP) series of reactions. The first step in this series of reactions is the activation of the amino acids. There is probably a separate activating enzyme for each amino acid.

$$\text{Amino acid} + \text{ATP} \rightleftharpoons \text{Amino acid AMP} + \text{PP}_i$$

in which PP_i indicates inorganic pyrophosphate. In subsequent steps the activated amino acid is transferred to an acceptor or carrier which further transfers the activated amino acid into the polypeptide chain that is to become the finished protein molecule. Although it is not yet possible to state exactly the point of interdependence of this series of reactions with nucleic acid synthesis, it is under investigation in many laboratories throughout the world. The proteins which are enzymatically active are presumably synthesized by the same pathway as other proteins. However, special interest attaches to the synthesis of enzymes because of the interesting problem of the amino acid sequence and the configuration of the polypeptide chain at the active site of the protein.

In most tissues the bulk of the protein consists of the enzymatically active proteins which catalyze the reactions characteristic of living cells. In seed, however, the bulk of the proteins present appears to serve the function of storage proteins to be utilized as a source of amino acid by the young seedling before it becomes established in the soil. See SEED (BOTANY). These reserve proteins are hydrolyzed by the action of proteolytic enzymes present in the seeds. In many seeds there is a manyfold increase in this proteolytic activity during germination (see PLANT GROWTH; REPRODUCTION, PLANT). As mentioned earlier, this rapid degradation of proteins to amino acids leads to the production of large quantities of ammonia which become incorporated into glutamine and asparagine. See AMIDE; ACID; AMINO ACIDS.

An interesting observation relates to the protein metabolism of excised leaves. The total protein content of a mature leaf remains constant or declines slowly as the leaf ages. After the excision of the leaf there is a rapid decline of the protein level. This decline is checked by the induction of adventitious roots on the leaf. See LEAF (BOTANY). These experiments suggest that the protein metabolism of leaves is partially under the control of some factor or factors produced by root cells. See ROOT (BOTANY). Such observations are of general interest because of the possible connection with the normal decline and senescence of mature leaves and fruit.

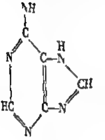
The infection of and multiplication of virus in plants is a special case of ... s of intrinsic interest. In

b c o mo aic ru the is a r pid synthe s of ru prote n Thi is a de no o synthesis from free m o acid rather tha fr m pre x sting leaf p te s On e the rus p ote n s f rmed t does not underg turn e that i there is no degrada ti n and sy thes of virus proteins *See* PLANT VIRU

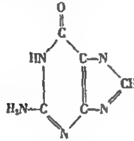
Purines pyrimidines and nucleic acids Pu r n and pyr mid nes are f importance beca e of th ir uni ers l oc rrence i li ng cell as com p t of enzymes a d n cle c ac ds

Th pu i ad nine and guanine are well kn n c n tit ents f nucle c a ids and f n cleo-tic cofact s such as ade osi etriphosphate d i ediph phate DPN TPN CoA gua o i e-t pho phate and guano i edipho phate Oth r pu (hypro nth e xa thine nd u ic acid)

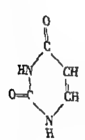
PURINES AND PYRIMIDINES



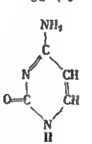
Ad nine



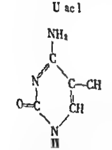
Gu i e



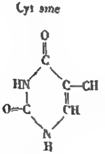
U ac l



Cyt sine



5-Methylcyt e



Thymin

f und pl t ha o st bl h d f t Th Py m d (u) yto n 5 m thyl yt ne d thym) l c a cl ot de fa t f mple d n d ph ph t nd n t ph s-phat d u d d ph sphoglu ose well a in) c d Th bi g f th p g ut l s t og f om the m d up f gl t m f m gly d f m sp t ti c d a d bon f m gly f m te nd c b n d d Py m d n r g b g l lt fr m th

dioxide and ammonia) in a series f enzymatic reactions

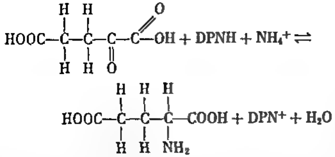
The ccurrence f the purine and pyrim dine ba es as nucleot de units in nucleic acids is f great imp rtance becau e tl e nucleic acids a such or combined with pr tein to form n cleoprotein are the carriers of genetic information Nucleic acids are h gh molecular weight substances con tai ing ma y nucleotide units linked as shown

Pur n ribo e phosphate

Pyrim d ne ribose pho phate

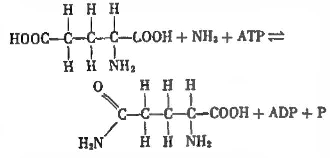
Ribonucleic acid (RNA) nta ribo e and are har cteri tic lly f und in the ell yt pla m wl rea deo yril ucl aci (DNA) c tain deoxyr bo e and are found nly in th n cleu (s CELL NUCLEUS CYTOPLASM) Th nucleoti le of ade e g anine cyt ine a d ur il are fou nd in RNA wherea th f ade i e gi ani e cyto-e thymine nd 5 methylcyt ine are f un l t DNA Exam natio f tl hydr ly i p odi t f DNA h f w th t th m l r rati of ade ine t thymin unity d th t the m lar rati f g a n ne t cyt ne + 5 m thyl yt i e i u ity Th app t p i i g of th purine d pyrimidine cle t de al ng w th the x ray d ff a ti n pat t rns f DNA h led to the important co c pt that th nucleotid hat f DNA are c l l i a d ble h l al structu The eq n f puri e nd pyr m d n ba es al g the DNA m l c le ar tho ght t b f g ifcan e elati n t the ge ti pr p-ert e f th m lecule M t t d visio clearl re-*qu re* m m hani m f r th e a t r pl t f tho e DNA m l l wl i h c rry h *redit ry traits* (e MITOSIS) Th sy the is of both DNA nd RNA i timately l ked to p tei ynthe i The d t rminat on of the a t m n f the yn th a d the inter el t on m maj p oblem f b logi al re ch *See* HETEROCYCLIC COM P UNDS NUCLEIC ACID

Alkaloids Of the alkal d r n tr geno b es whi h h ve a w despre d occurr ce i the pla t k gd m ly the p i es and pyrim d nes ha e og d f t o The oth are thought to pr t end p du t f n t gen metab l m H st lly man s kn wl dge f d i re e t i the lk l d tems f m th pl y i l g c l ffect on m) N e t d or t f t b ec tro-p *f At op Dat* a d *Hyoscyamus* the got lkal d f om the f g s *Cla eps p pu* and p e f m *R u lfa* e e mpl of lkaloids that b be n *eful* a pha m col g cal age ts I the t b c pl t c t d o n ti (F g 11) a ynth zed by ot a d t n p rted to l a s O th ne the pr r f the py r l d n ti ic c d Th m thyl gr up may come f m m th i f m th β a bo of Atro-



line and hydroxyproline cannot be formed by transamination reactions Proline is formed from glutamic acid by way of glutamic acid semialdehyde and pyrroline carboxylic acid Hydroxyproline is formed by oxidation of proline Higher plants are able to synthesize all the amino acids which they utilize in their metabolism Some of the lower plants and some bacteria are not able to synthesize all the amino acids which they require and are therefore dependent upon plant and animal residues to supply these preformed

Although ammonia is an intermediate in the metabolism of living cells ammonium salts are extremely toxic if allowed to accumulate in the cell Living organisms prevent the accumulation of ammonia by excreting it or by combining it into some innocuous compound Higher plants incorporate ammonia into the amides glutamine and asparagine Glutamine is synthesized by the following reaction



The exact manner in which asparagine is formed is not known *See* ASPARAGINE

In seedlings especially etiolated seedlings a dominant feature of nitrogen metabolism is the formation of glutamine asparagine or both This synthesis of amides is a result of the high level of ammonia produced during the enzymatic hydrolysis of the seed proteins and the utilization of the amino acids to supply energy and carbon skeletons for the synthesis of new cells in the seedling As the seedlings develop and the level of ammonia drops the amides gradually disappear as their nitrogen is utilized in the synthesis of other amino acids to be used in protein synthesis

The prominent feature of the nitrogen metabolism of any growing cell is the synthesis of the cellular proteins Because there may be as many as several thousand different kinds of proteins in a cell it is obvious that protein synthesis in a rapidly growing cell is a result of very complex processes Proteins may differ from one another in amino acid composition in amino acid sequence and in the three dimensional folding of the long polypeptide chains The e characteristics are of course under genetic control (*see* GENETICS) Some of the most interesting developments in biology in this century center around the discovery that the genetic material of cells consists of nucleic acids and of nucleoproteins and that the biosynthesis of proteins and nucleic acids is interdependent and simultaneous.

Proteins appear to be synthesized directly from amino acids by an energy dependent (ATP) series of reactions The first step in this series of reactions is the activation of the amino acids There is probably a separate activating enzyme for each amino acid

$$\text{Amino acid} + \text{ATP} \rightleftharpoons \text{Amino acid AMP} + \text{PP}_i$$

in which PP_i indicates inorganic pyrophosphate. In subsequent steps the activated amino acid is transferred to an acceptor or carrier which further transfers the activated amino acid into the polypeptide chain that is to become the finished protein molecule Although it is not yet possible to state exactly the point of interdependence of this series of reactions with nucleic acid synthesis it is under investigation in many laboratories throughout the world The proteins which are enzymatically active are presumably synthesized by the same pathway as other proteins However special interest attaches to the synthesis of enzymes because of the interesting problem of the amino acid sequence and the configuration of the polypeptide chain at the active site of the protein

In most tissues the bulk of the protein consists of the enzymatically active proteins which catalyze the reactions characteristic of living cells In seeds however the bulk of the proteins present appears to serve the function of storage proteins to be utilized as a source of amino acids by the young seedling before it becomes established in the soil *See* SEED (BOTANY) These reserve proteins are hydrolyzed by the action of proteolytic enzymes present in the seeds In many seeds there is a manyfold increase in this proteolytic activity during germination (*see* PLANT GROWTH REPRODUCTION PLANT) As mentioned earlier this rapid degradation of proteins to amino acids leads to the production of large quantities of ammonia which become incorporated into glutamine and asparagine *See* AMIDE ACID AMINO ACIDS

An interesting observation relates to the protein metabolism of excised leaves The total protein content of a mature leaf remains constant or declines slowly as the leaf ages After the excision of the leaf there is a rapid decline of the protein level This decline is checked by the induction of adventitious roots on the leaf *See* LEAF (BOTANY) These experiments suggest that the protein metabolism of leaves is partially under the control of some factor or factors produced by root cell *See* ROOT (BOTANY) Such observations are of general interest because of the possible connection with the normal decline and senescence of mature leaves and fruit

The infection of and multiplication of virus in plants is a special case of synthesis of intrinsic interest In tob

D M El y and B Gla s (ed) *Ino g c g M tab l m* 1956 R R l *The ct l Rel t o s of Nat l Pr d cts* Weiz Mem l Lect 1 195 G C W b ter *g M t b l m Pl ts* 19 9

ant morphogenesis

b l g l e c cerned w th the gin and el pm t f the f rm and t ct r f pl t de l w th tho e ph me a both t rnal a d tern l by h ch f rm d term ed Otl e n me metimes g e t m rph gene perimental ph l gy ca l m ph l gy expe ime tal m y l ry d *E t M e m h k*

F rm s th e h of th rderly gr wth f s d m n Th f rm of the b dy a d f ch ru tures lea es fl we h a d cell are mples f th s e t lled dev l pment F rm and ru t e l g th g e s ble expres ons of g zi g charat f l feat ery le el

Correlation Th general t rm f the re t n h p m th parts f g m esp lly d ri g t dev l pme t M t bod ly pa t o t bo t the m r te th f rm does n t lte gr tly d ng developm t l m a e e pa t gr w fa t th n the pa t or d me f te th n a th E he e th el t h p m ng gro th t r m fa rly n t t s th t f rm chang a r g l r and ed s bl fa h Someti m the phy al ba f rr lati n i e dent For mpl t rm l b d m y h b t gre tly r i d th gr wth f b d b l t

Polarity l lm t ll ms an ap d ri g de el pm t a d t tw end b m d t oot d hoot i h gh pla t Thi m b ery ly ev n the f rt l zed gg tt If It i e d nt g e t P la ty al ap physi l l p es In m y e th d e d g ade t r te f m tabol c p oc es f m o d of th t th the Mov m t f ub t es ma l be p l r It ha b ug t d th t b el t l f t ar n l d pl ty I m a g m t f m t al by ce trif t n h been fo d t h g th p l r nd t m y b e e d by th n

Symmetry Th g m t f l te al t c t a d th m pola n t rr g l b t h p tt rn f ymm try f rt Most pl t e rt cal d the d t l t f l d th m (phyll t y) s l l d p The p t f tt hm t f l s m v b pp t h l d d n d n p al (lt S h p l f ll t d fi te l h h h mpl thm t l l t h p t n th

Wh the a h zo t l the pp d des lly d ff t (d nt l t) The t t th ght d l ft d lly m m g of h the (b l t l ymmet) O g n ymmetry f l p th th t of ry tal t h h t h m t m b mp d

Differentiation A n pict u fact f level t m nt i tl at d r g at r the t rt f th r g m l ec m differ t fr m n a ther An x ampl of h diff tiati n tl at l twe n tl tw end of tl e p l r axi D el pm t in h gher plant t acc mp nied l th pr g e s apl ar a ce f di ti t rgan —roo t t m l a es fl w r fruit a d eed —tl e utward g f h i i n f l bor within tl pl nt Cr wth a d d fferentia t generally p oceed t g ther l t th re a e c es where e occurs w th ut the ther In tl e co rse f tl e life y le f a rgani m diffe ntial changes cc ir in a definite eries f t g

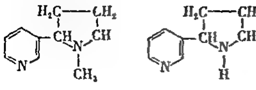
Int l d ff r tl at ri m g ti ie and m g ell d ring d el pm nt ar a marked a t e t l f m S m tim h a diff r n an l tra ed t a part la cell d n s wl h tl e tw d ght r cell are nl ke In m r pr m t rga m d ffe t t n p oceed a a r of h di i n l t i m t es th p eci p int of origin of the e differences is hard t loc te Par t l ttern f i t l tructural d ff l e an h red t ry ba i b t ar ften mod fied l y fact rs in the inter al or e tern l en i nment F within a s gle ell ther ften a d l le degree f d ff re tiat n am ng t part Tl fact th t ell lly ha e th am n mber f ch m mes a the f t l ed gg f r a mple m lt ple f these l gge t th t tl e g t c n t t on of ry cell i like th t f all tl Why d ff ence ho ld e am ng them th efore eem t be du e ther t d ffer t exp e to ex t l fa t rt chang in tl cyt pl m f tl e ll

Physi l g cal d ffer es l etwee part f the pl t are mm Cell f th r t ar nal le t the i ga d erta the nec a y b t es d m t get them f m the hoot Many l l zed phy l g l d ff n are m nt ned bec e f th mp me b lity f the ell mem b a t b t esp od d i th ell

Regeneration Th b l ty of m ny rg n m g i lly d g th l devel pme t l t ge t epl c l t p rt i di t nctı ph n m n of m rph e C tt g fr m the tem f m n pl t w ll p d o t f pl e d n a f able i o me t

Tho gh th p te y bec m p ogre i ely r t ted n m l a the d du l m t r t m y m i alm t defi t ly i pl t In ma y a s m t r pl t ll wh h h e be d c d by h m alm t d d g i w ll the e r t mall gr w g p t f m wh ch wh l pl t m y be f rmed S m pla ts n tu lly ep od c th m el e by m ll pl tlet p d ed f m m g ll f lls

Atypical growth The gan zi g ntr l nd r wh h pl t d l p m y met m b k d wn g th p d et f g ll t m d th ab m l f rm Of p rt l m rpho g t i t t e gall f rm d n pl ts e c t t t i t t mul t espec lly f om the y p d w ps Th ll a u ually f a ry



Nicotine Nornicotine

Fig 11 Structural formulas of nicotine and nornicotine

lates in the leaves Very little is known of the biogenesis of the many other alkaloids The determination of the manner of their synthesis of the conditions under which they arise and of their possible function in plants would be a significant contribution to plant metabolism See ALKALOID

TERPENE METABOLISM

Oils resins and carotenoids The terpenes and their derivatives may all be considered as being derived from isoprene This group of substances includes essential oils resins the carotenoid pigments phytol and rubber Probably all plants are able to synthesize some of the carotenoid pigments

$$H_2C{=}CH{-}\underset{\displaystyle CH_3}{\underset{|}{C}}{=}CH_2$$

Isoprene

$$-CH_2{-}CH{=}\underset{\displaystyle CH_3}{\underset{|}{C}}{-}CH_2{-}$$

Repeating unit of isoprenoids

and phytol (the C_{20} alcohol present in chlorophyll) The ability to produce significant quantities of essential oils and resins however is much more restricted in the plant kingdom perhaps to 2000 of 400 000 species The oils and resins are produced by specialized cells or groups of cells and may either accumulate in these cells or be secreted into resin ducts See SECRETORY STRUCTURES PLANT

Carotenoids deposited as plastid pigments occur in roots stem leaves flowers and fruit In green leaves the carotenoids are associated with chlorophyll in the chloroplasts (see CAROTENOID CHLOROPHYLL) The carotenoids are synthesized in the tissue in which they are found and transport does not seem to occur Acetate as acetyl CoA appears to be the precursor of all the isoprenoid compounds The intermediate steps probably involve first the formation of acetoacetyl CoA then the formation of the 6 carbon compound β methyl β hydroxy glutaryl CoA which is converted into a 5-carbon compound that can react with itself to form compounds containing 10 15 20 30 or 40 carbon atoms See FAT AND OIL, EDIBLE FAT AND OIL NONEDIBLE RESIN

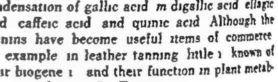
Rubber Rubber occurs in hundreds of species of plants and may constitute up to 20% of the dry weight of the plant It occurs as small particles suspended in an aqueous serum This suspension or latex occurs in and is formed in specialized cells or vessels The latex which is obtained by tapping the *Hevea* tree contains all of the enzymatic apparatus necessary for incorporating radioactive acetate into rubber The repeating unit in the chemical structure of rubber is isoprene

Although the deposit of large quantities of rubber in the latex vessels of plants represents a possible source of energy for the plant there is no evidence that it does actually function as a reserve food See RUBBER

OTHER METABOLITES

Tannins The tannins are a group of astringent substances apparently formed by the condensation of phloroglucinol and its derivatives or by the condensation of gallic acid m digallic acid ellagic acid caffeic acid and quinic acid Although the tannins have become useful items of commerce for example in leather tanning little is known of their biogenesis and their function in plant metabolism is unknown See TANNIN

Anthocyanins and flavones The water-soluble pigments of plants consist almost entirely of anthocyanins and flavones These pigments occur largely as glycosides and yield on hydrolysis a sugar and a 2 phenylbenzopyrilylium derivative (anthocyanidin) or a sugar and a 2 phenylbenzopyrone (flavone) derivative A great variety of anthocyanidins exist These differ from one another by the degree of substitution on the β ring by the total number of hydroxyl groups by the degree of methylation of these hydroxyl groups and by the number (1 and 2) and kinds of sugar residues linked to the anthocyanidin by the glycosidic linkage Similarly a wide variety of flavone pigments occur in plants These pigments (Fig 12) are generally produced



2 Phenylbenzopyrilium (anthocyanidin) 2 Phenylbenzopyrone (flavone)

Fig 12 Structural formulas of 2 phenylbenzopyrilium and 2 phenylbenzopyrone

by plants under high light intensity and low nitrogen and phosphorus supply In some cases however pigment production is independent of light and may occur in roots or in etiolated seedlings Although the chemistry of these pigments is understood little is known of their biogenesis and nothing of their metabolic function See ANTHOCYANIN FLAVONE GLUCOSIDE see also PLANT PHYSIOLOGY

[J E V]

Bibliography J Bonner *Plant Biochemistry* 1950 M Dixon and F C Webb *Enzymes* 1958 J S Fruton and S Simmonds *General Biochemistry* 2d ed 1958 O H Gaebler (ed) *Enzymes Units of Biological Structure and Function* 1956

m t pronounced effects on tho e structures that are mo t r p dly developi g at tho e t ges They m y di turb the correl ti e ffects between struc tures o alter hormo e d stribution

Chrom s mes i fluence development apart from th ge they carry In members of a polypl id s nes n pl nt fo e ample the ize of the organ i m p rts nd its cell is often proport onal t the number of chromosome sets from 4n down to 1n. The larg r the number of ets al o the sho ter the p la diameter of l a and fruits tends to be s mpared the equatorial d ameter S e PHOTOPERIODIS I IN PLANTS PLANT GROWTH PLANT HORMONES [E W S]

B bliog aphy J T B nner Morphogenesis 1952 K. Goebel E nleitung in d e experimentelle Mo ph l gie de Pfl nzen, 1908 D W Thomp on On G o th d Fo m 2 ls 19 2 C. W Ward law M ph g n is n Pl nt 1952

Plant movements

Mo eme ts of tt hed membe f n nmot le pla ts d d d nt two e teg ri s thos h h re p es to exte n l t m l nd th e wh h e lt f m t mul of nt rn l rig n If p es t ternal timuli are med ated by th th y e kn wn e th r as trop e r a t e m t

In the trop c e p s th d ect n f the cu t re o mo m t s dep d t n the r nt ti f the st mul s The f d m t l f t re f tr p t m l t is the p e d t butt f th gy which i ppl ed The t p curv tu a b ught bo t by eq l el g t (gr wth) t o ppo t des of th plant o gan wh ch t m re depe d t p n the eq al di t bu ti n of g th ubt n e e lled au n (s AUXIN) T p c rv t n re ther tow rd (po trop m) m way f m (neg ti tro- p m) th f t mul t

I co t a t to th trop ms gr wth m em nts (pl m m wh h th pl nt comp nent r p n e is determ d by the tern l truct but w thout r l en t th r t t o of th st m lat n e e y a defi d t m em t Re p ses f tt h d m mbe f onmot l pl t to t mul f te lo g m y be d pe de t o d p nd t f gr wth El g t t p m n t ti n a d e i n n ti p s d pe d t on gr wth wh pe l d pul m em t (d u d l t de tu g m m t) m d t d by m h m othe th n g wth S e LEAF (OTA Y)

I dd t n m eme t f m til rgan m or f e pl t part i re p t e t rn l t muli ar k w a t t em nt Th re di t ng i h d f m mo m ts f m l g m pons to t mul f ternal r g n wh h met me i rmed a t nom lo m t

Pl t m em t w ll b d c s d m th f ll wing o der ph tot p m geotr p m el c t t op m th gm t p m h t t p m tr m tot

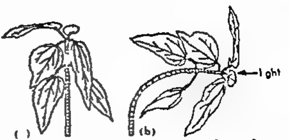


Fig 1 P ti e phot t opi m (a) Ap of u flowe pl t w th it st m ma k d at equ l i tervals (b) Sam pl t ft ho g be ill mi t d o side Be d i g o rs in the n f l got n (F m G M Sm th t al A T xtbo k f Ge l B t y 5th d M cm ll 1953)

r p m hydr tr pi m chem tr p m n tic mo e- ment t ctic m v m nts nutati n a d turg r m me ts

Phototropism The bending f plant rgans me- diated l y u eq al g owth rates of the ppo te de and d rected t wa d away fr m th so rce of vi ble light s alled ph totr pi m (F g 1) O d nar ly tems and other aerial orga r po i t ely p h t trop wh ea roots nd imilar str c t re re p d neg t ely Se ROOT (BOTA Y) STE I (BOTANY) Thi general zation h wev r h a n mber f e cepti It is kn wn th t some tems e n g t ely ph t trop me root a e po t ely phot t opi the a e n nph t t pic Som st uct re uch as the A a leoptile (a w dely sed mate al f r the tudy f trop m) e e ther po t ely r neg t ely ph t tr p c d pend g up n the m u t of incid t ergy Low do g of l ght (100 m t r-c ndl e nd) i duce po iti e be di wh I i known as the fi t p t ve c rvat re Much high d ages f l ght m y a e the pos t e neg ti e tr p m How ve l ttle kn wn bout n g ti e ph t trop c u rva ture f tems

I At leoptiles nd rt in ther tem d oots the u trem ap x the m st e t to l ght Rem l f th t p r lt in a s dd n l o d mi t of ph tot p c n t ty Bec u e p marily the p al ells o cerned with th p d t n f x the apparently a l e el t n h p b twe p od t and ph to- t p it ty

U late l light f ll g the ti s ab b d by p gm nt nd a light g d e t is es- t bli h d c o the o g The phot e ept is y ll w p gm t b t t p fi d t fi at n has t been m de Th b t e d e d at that eith bofl v e otene abs bs the ad ant rgy wh h med t s th fi t p t e curva t (e CAROTENOI RIBOFL VIN) Aft r the d nt nergy h b e b bed it m t me way m d t e e of au n m the had d de f th l optile It m th t phy l ti ty b tw th ll m ted and h d d s de e e t al fo r xim m e t r t de l p a d that

specific shape and internal structure which vary with the particular insect and the plant species Substances introduced by the insect or formed from the larva hatching from its egg evidently have a very definite morphogenetic effect Certain rather formless plant galls the crown galls produced by the attack of various bacteria have some resem blance to animal cancers

The most extreme case of disorganization occurs in tissue cultures where single cells or formless masses of tissue continue to grow without develop ing into an organism

Ecological factors Various factors in the or ganism itself or in its environment have been found to be important in the determination of its form and structure Since most plants are station ary they are in general more susceptible to en vironmental influences than are animals which can move from unfavorable to favorable surround ings Some of the more important external and in ternal factors are di cussed in the following para graphs

Water This is of special importance in plants In relati ely dry soil the cuticle of a particular species tends to be heavier and the tissues more woody and made up of smaller cells This is now thought to be a direct effect of water shortage on differentiation In plants which can grow with their shoots either in air or submersed in water the dif ferences in development and structure under the two environments are very marked

Temperature An important effect of tempera ture on plants has been found in the early growth of the eedling If sprouting seeds of grains and some other plants are exposed to relati ely low temperatures the early developmental tages are pa sed through rapidly Seeds thus treated when placed under normal conditions produce the final mature state of the plant much earlier than un treated ones By this proce s called vernalizat on winter wheat will grow to maturity as soon as pring wheat

Light This factor is of particular morphogenetic importance in plant Vegetati e de elopment is affected by intensity of light l w inten ities in ome ca es producing spindly or eti lated growth The quality of light is also influential The red end of the spectrum tends in many ca es to stim late growth of reproductive structures and the blue end differentiation and vegetative growth

Important in the production of floral organs is the duration of exposure to light or the photo period Where this is relatively long in relati n to the dark interval flowering i stimulated in long day plants In short day specie howe e fl w ering occur only when the daily ph toperiod i relatively short and alternates with a long uninter rupted dark period The factors in olved in the transformation of the vegetative to the flowering tate are not all well understood l ut the pro duction and transfer of specific sub tances which influence differentiation are probably inv lved

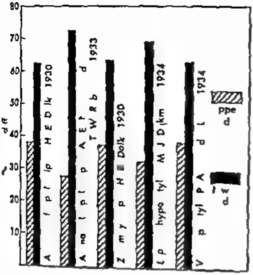
Mechanical factors Stres es and trains of vari ous sorts have ome importance in development Gravity through its effect on the di tribution of substances affecting form influences various geo tropic orientations in plants A tree swayed by air currents tends to have its wide t diameter in the plane of sway A tree guyed firmly by cables will not grow in diameter as fast as one that is un up ported

Chemical substances Chemical factors of many kinds affect development Sometimes the result i very specific and radical as when a teazel plant grown in soil of high nitrate content develops a much twisted stalk instead of the traight one formed in ordinary soil The relative amount of substances may al o be important Thus plant in which the ratio of carbohydrates to nitro en i hi h will tend to produce flowers and fruit but uch plants will usually form only vegetative organ when this ratio is low

Hormones and growth substances Certain more complex chemical substances e pecially the chem ical mes engers or hormone profoundly affect development in plants Various ub tance ha e been found in plants which control development Most notable is auxin indoleacetic acid which ha various effects It stimulates or influences cell wall elongation particularly in the early tages of de velopment and thus plays a role in mo t of the bendings or tropi ms of plant made in re pon e to gravity and light It stimulates root de elopment cambial activity and the growth of eedle fruit It may inhibit the formation of the corky (ab ci sion) layer that causes leaves and fruits to drop off Auxin in a terminal bud prevents or retards the growth of buds below it for a certain di tance from the apex and thus affects the branch sy tem of the plant It is invol ed in the formation of crown gall tumors Many of the e effects may al o be prod iced by arious synthetic sub tances chiefly other or ganic acids

Grafts and chimeras In plant chimeras the tissues of two individuals may be intimately com bined either naturally or artifically The two outer cell layers of a plant may be deri ed from tomato for example and the remainder from night hade or vice e sa These are related but quite di imilar species and the contribution of each to the form of leaf flower and fruit may thus be determined No genetic union is produced and the ex cells formed by the chimera will l e identical with tho e of the pecies that pro ides the layer of cell ju t under the epidermis

Hereditary factors Many single gene ha e been found that contr l the form of tl e l ody r of its part The shape of leave flower and fruits in many plants are examples of form that are gene contr lled Such gene evidently c ntrol the rela tive rates of growth in ariou directi n Where f m changes with ize genes for size will e idently ha e an indirect effect on f rm Gene tl at check growth at particular eml ryolog cal tage will ha e



Fg 3 C p t p c tog f upp d l d of y g st m t p

t tion f pward curv tu and th development of th p larity i depe d nt f n con ent a u n. Also th e here t bs ele t e l p l t e an b es r bly hunt d by the e of v ri u d l t l tion f el ctr lytes Su h t tment al o h b t g tr p curs tu

An th s w th t g ts e th d pla e m t f a t t l th su h a t ch gra l wh h rat rn by som mech n m wh h ha t been re-aled event lly b t g bout the x t an loc t A stat lith c ld e bly f n t n w th n and d l ell b t at i d ffi lt t d r ta d b w t m ght be i [d the t sp t of a n f om c ll t the xt

Th ta d d expla ti f p t e ge t op m ba d n th pr m se th t t t l x n ce t t f th r t i ab th pt mum for g wth t m l u n. Th mpl t that y b g e t i a. m e nt at u nh bit m of g th Th n incre a th l w r h lf f th root i d c d by g t I t m l t n inh b t gr th of th s h lf S m l rly a decr m u t t f the pp r h lf a es n i the rat f el g t on The c mb ti n f th hanged lo g t ate e lts d wn w d c rv tu

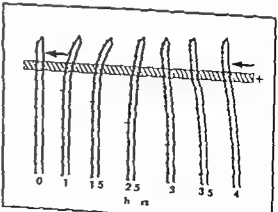
It g er ll a epted that a x mo s f m the upp to the low h lf f th ro t t p n lf h th root pl ced th h nt l p t n f th way the pply f a x n t the longat ng ll dec es i the ppe h lf d ea e i th lo The m han m wh h pon l le f th a xin m ment i th t p h t b en el d dat d Th r i l m t d d po ti g to the p b l ty that ge t p t m lat lte th tate of ynthe nd th p d t f a nd gen s nh l t f gr wth n the lowe half f th oot h b n gg t d H we th fu d m t l g h an e of th pr n p ti geot p m ha n t b e te ly luat d

Plag tropic struct ire uch a l teral tem and econdary r t l ave th ir l ng axi inclined ll pt ely away fr m th ertical xi l the plant The term d age tr p is applied to ucl truc ture a rh z mes wh tle angl f rmed with the vertical axis i a r ght angle The p tion main tai ed by the ariou orga vers lik l a ma ife tati n f a mpo ite re p n e t a nu mber of stimuli i l ding geotr p c timulati

Electrotropisms G wtl cu t i e t p n e to t a er ely appli d d rect curr nt ele trical field are called electr tropi m I the *Ave* coleopt le the l ending i toward the electropo i t ve p le of the timul ti g cir u t F g re 4 sh w electrot op curvat es t th i dicate l tim after t m lat wl e u rr t wa appl ed ll mm bel w the apex In the range of 5–30 μa applie l f r 2 m n the magn tu le f curvature i depend nt i pon th rr t trength Decapitated an l auxin-depleted u leoptile dc n t r p nd t d rect current Add i al indirect eviden e in l cate that electro-tr p c curvat r of tem are med ted l y growth mech m which req auxin

Aux d pleted cole pt l which ha e 3-i d le-a t a id (IAA) applied t tl p l end will e p nd elect tr pically m h the m wa a i ta t edl y The magnitu l f rvature i d re tly depend t on IAA n trati n t a maxi m m f 0 8 mg/l ter It h been d m n trated that l ctrotropi c r atur are m d t d l y th a ym m t i d tributi n f IAA wl h i l r ght ul t by lateral t n p t A tate f p la ty in th plant t r th er th the fl w of ternally applied cu re t is dir tly respon ibl f r th tran loca ti n f the IAA It s not pparent why the IAA sh ld be tr port d t w rd the side that wa mad electr n gati by the appl d c rent

Thigmotropisms Cur at e p e to me ch al t mulati n e called th gm tropi m Wh *At* c leopt l or t ol ted edl ng o te d ls re tr k d or l ghtly tapped n one ide th e p d by b d g t wa d the stimul ted d Be a se s ch resp n d n t o cu in co-le pt l s d pleted f a xin these curvature p-p re tly i l e d ffe tial g owth ates au ed



Fg 4 Elect t p rv t s f A c l pt l

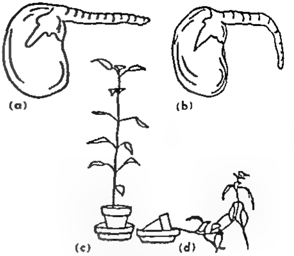
ome means of amplification is necessary to ac count for the differences in auxin concentration Three possible mechanism could be involved in the attainment of the asymmetry of auxin di tril ution

The first mechanism requires the more effective photode truction of auxin on the lighted ide Ac cording to the original ob ervation made by F W Went do ages of light which induced the fir t posi tive phototropic curvature cau ed the total auxin production to be lowered from 100 to 84% (Photo destruction of auxin in vitro also has been demon strated) The auxin content of the lighted ide ap parently is lowered to 27% (compared with 50% in a dark control) whereas in the haded side the content apparently increased to 57% In other ex periments the ratio has been reported to be as low as 11 to 89 Thus although it is apparent that *photode truction of auxin may be involved in pho* totropic curvature to ome extent differential de struction of auxin by light presumably does not function as an amplification mechanism It still re mains important to explain how lateral tran port of auxin can be effected

The transport of auxin against a concentration gradient requires an oriented force Becau e auxin is an acid which will migrate tow ard the positive pole in an electrical field the po sibility of such functional electrical polarity has been proposed It is known that unilateral illumination by white light cau es the extreme apex of the *Avena* cole optile to e tablish a transver e electrical polarity such that the lighted side becomes electronegative to the shaded side Such polarity would cau e the auxin to be transported to the positi e and shaded side It has been hown that tran ver ely applied direct current can induce lateral transport of auxin In po itive phototropi m this viewpoint is further supported by the fact that externally applied ele trical fields can increa e or decrea e li ht induced bending depending upon the polarity of the elec trical timulation Lateral transport of aux n cau ed by the photoinduced transver e electrical polarities re nains as a pos ible but not the only explanation of positive phototropic curvature

It is rea onably well e tabli hed that vi il le light alters auxin synthesis in various plants The ex treme apex of the coleoptile is the ite of auxin synthe is Thu it is po sible that the unequal dis tribution of auxin i brought about by an asym metric auxin synthe is All that is required i more effecti e de truction or inhibition of an enzyme or cofactor required for the synthe is of auxin in the illuminated ide (*see* ENZYME) This would all w the auxin precur or to *accumulate on the lighted* side to such an extent that it would rapidly diffu e to the haded ide where it could be converted to active auxin Such a eq ence would decrea e the auxin concentration on the illuminated side and increa e the auxin concentration on the haded side re ulting in po iti e curvature The evidence which upports this concept al o is indirect

Because roots normally grow beneath the surface of the oil there is very *little functional* ignifi



Fg 2 Pos t e and negat e geot p m ( ) A bea s edl ng whose pr mary oot has bee ma ked at equal intervals and placed a hori tal pos t on n a moist chamber (b) Sam seedl ng 24 hours l ter B d ng ccurs the re on f longat on (c) A pl t of Ir ene i an upright pos t on (d) A pl nt wh ch ha been t ned on t s d In l e e the negat ve geot op c respo s to st m l of g a ty co ts p m c pally n upwa d c rvatu e of the yo ger odes (F om G M Sm th et al A Te tbook f Ge l Bot a y 5th ed Macm llan 1953)

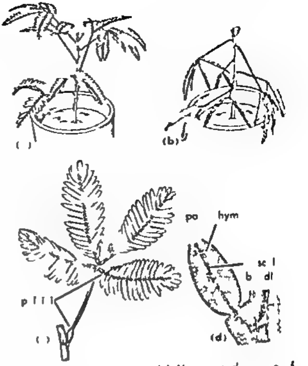
cance of the phototropic re pon es of the e organs It seems reasonably certain that an a ymmetri di tribution of auxin is es ential for phototrop m of root but it is not clear how such lateral di tribution is brought about Furthermore the auxin to growth linkage remain relatively ob cure

Geotropism The curvature re pon e of plant components when they are placed in the *horiz ntal* position is called geotropi m Primary roots bend toward the force of gravity hence are po itively geotropic (Fig 2) Shoots or stems bend upward and away from the force of gravity and thus are negatively geotropic Geotropic curvatures are brought about by unequal rates of elongati n in the upper and lower hal es of the organ As in phototropism the e unequal rates of growth are in turn dependent upon asymmetrical *di tribution* of auxin Becau e a direct chemical effect of a change in the direction of the force of gra ity is mo t un l kely the problem of lateral tran port ha oc cupied the major share of attention

In negati e geotr pi m most of the available information indicates that tran er e mo ement of auxin is indeed accomplished A ample of such data is shown in Fig 3 Only fragmentary e i *dence contradicts this viewpo nt Elucidation* of the mechani m required for the lateral tran port of auxin again has paramount s gnificance Se eral po sibilitie ha e been ugge ted

Structures which are negati ely geotropic e tab lish a transverse electrical polarity when they are placed in the h rizontal po ition The lower d becomes electropo iti e to the upper de Such polarity is establi hed l efore the unequal di tril u tion is po ible the p larity s long before

ot s Chem ta ll mo ement are th e
n f ee plants r pl nt p rt migrate toward
e) or a ay fr m (egat) a spec fic
al ub ta e Chem ta ti mo ements a e
ed by ome gam tes a d u h f m as the
ba f the Ac as le
tions Rhythm al or p r d m eme t
e h bited by hoot ape es of pl nts ar
n tat These auto mic m eme t are
s q e e f inte ally d ced ri ti n f
r te i diff re t p rt of th tru ti e The
t n t ti s e the oddi g m t ons f ac
gr w g ape e f s ch mp ne ts as th
yl f b s *See* SEED (BOTANY) The e
a med ated by alter ti n gr wth
pp te s de f the ep c tyl In a lightly
i l d ut t o kn wn s e rc m t t
l t t p ppe to be gr w ng upwa d i a
ght l e when b erved w th the n ded ey
eve al ght m fic tio eveals th t th t p
lly d b an i reg lar r sp ral path a the
g w Th se m em t e l o d ced by
t gr wth tes d ffere t gio s f
espo d g truct Tw ni g m y b iewed
g ted f rm of ir mnutati n Stem
f tw g pl t such as m rn g gl ry and
l ed re gener lly lo g sl der nd with t
es Becau e pp t g t sue s n t w ll d
ped th t p f twi i g pl t f eq e tly be d
t app m te the h zont l p t on As n
t p m a i appa e tly m lat in the
h lf f the tem (p hap rtly a re lt
g t op t m l t) Mo e r p d gr wth
l w d t p rt n f the t m e
d p al g m ement f th t p a d res lt
twi ted st m
Turgor movements A few pla ts wh ch bel
h f m l e the Legum ae h e p al
ruct c ll d p l i l ted at th ba e f the
d p t l (s LEGUME) Wh tum
t d th p l ch ge th r h pe a the lt
f t g ti d th by ind pid m e
n t f the pet l a d le The rat f tra
n f th mp l t pl t f m th
o t of t m lat t th p l ge f m
b t 2 t 15 mm/ S m e d d te
h t h rm m h m a f t al in m
p l d t (F g 5)
l *Mm* th t l l b ndl
h p l f th l f d the s b twe n
th rr d g p hym t ll a l g
(PARE CHY A) Th ll w ll f th e
hym l y th k th pp h lf th n
n th l h lf f th p l It kn wn th t
ert n t p e e t p l p t
t m lat St m l t f *Mm s* th o ll d
t pl t c w t t p t the
te ell l sp ce th t th l s f t rg r s
t the l wer h lf f th p l n wh h
mb at n w th th te th uppe h lf f
th p l lt a h ge i h pe f th
pul Th h g p l a h p the
f th m me t f the tt ched p t le or



Fg 5 T go m em t ( ) *Mm* p d e f th t pl t (b) Pl t f *Mm* ft le fl ts d l h po d d t m h i l t m l ( ) L f f *Mm* h w g the p l t t b f th p t l d of h p m ry d d ry l fl t (d) L gthwi ct f p l f *Mm* d g m m t (F m G M *Sm th t l A T tb k f G l B t y 5th d M m ll* 1953)

leaf *See* PLANT GROWTH PLANT HORMONE PLANT PHYSIOLOGY [A R SC]

B bl og phy P Boy en Jen en *G th hor m t pl ts* 1936 A C Leopold *A xi s d pl t g owth* 19 5 F Sk (ed) *Pla t G wth S b ta ces* 1951 F W We t d K V Th mann *Phyt ho m s* 1937

Plant names

There tw types f pla t n m th c mm n n n l r d the l al t whe e the pl t g ow d the ci t fi Lat n used by b ta st e ally Since comm n n mes for the m pl t ofte ary n differ t l c l tes and ce m ny pl t ha e no comm n m s while the h t m y mm name u s tis fa tory f e t fic pu p e

M y f th t fi name g nated com m n n me used wid ly n the days f the an ent R m Emp f e mpl *S l* (w ll w) *Q* (k) *Rosa* (r) nd *F l* (ol t) Th e n m we r ed dire tly nto b ta cal wr t g f the si t th a d ente th centu ie Som m on e wa peri d wh n a gl Lati n m des g ted se l sp es f pl nts f t ce n m ou pecie f oaks f e f let I ch ca t w ry to dd ad j ct es t de ign te th diff ent pec s Som

by auxin. It is known that mechanical stimulation can inhibit or prevent negative geotropism and positive phototropism and that such stimulation induces a transverse electrical polarity in the *Avena* coleoptile. The stimulated side becomes electropositive to the opposite side. Thus the assumption is that an asymmetric distribution of auxin is implicated in thigmotropism and that such distribution is mediated by lateral transport to the electronegative side. Neither of these assumptions has been verified.

Haptotropism. Some plants classified as nonclimbers have ordinary structures such as the petiole, leaf tip, or specialized tentacles that are sensitive to contact stimulation. It appears that growth of the cells on the contacted side is inhibited, whereas the cells on the opposite side continue to grow. This combination results in a sharp curvature, and the plant structures grow around the object which was contacted. Curvatures of this type are defined as haptotropism.

Traumatotropism. The curvature of plant organs toward or away from a wound or an injured area is known as traumatotropism. Most curvatures of this type are positive; the direction of bending is toward the wound. These responses in stems and roots are commonly explained as being induced to a large extent by interference with the mechanisms for the distribution of auxin. Additional factors, which likely are involved to a lesser extent, are the interference of the upward translocation of food factors and the possible destruction of auxin by substances released from the wounded cells.

Hydrotropism. The growing of roots toward wetter regions in the soil is called hydrotropism. This type of response can be demonstrated by growing the roots of certain plants in a moist porous material in a shallow tray with a wire mesh bottom. The roots first grow downward and through the wire mesh. They then bend back, away from the dry air below and toward the moist air. In order for this to happen, the hydrotropic stimulus must overcome the effects of the geotropic stimulus.

Chemotropism. The growth response of plant structures to chemical compounds in the environment is defined as chemotropism. The tubes of some pollen grains, when allowed to germinate on nutrient agar in which pieces of pistil have been embedded, will grow toward the pieces of pistil. It is presumed that substances which attract the pollen tubes are diffusing from the pistils.

Nastic movements. Curvatures or movements caused by external forces but whose direction is determined by the internal structure of the responding plant system are called nastic movements.

Epinasty. In epinasty the leaves and stems always tend to curve downward regardless of the orientation of the stimulus. For example, in the stems of *Tradescantia*, when the lateral branches are in the vertical position, auxin is transported only along the dorsal side. When the branches are in the horizontal position, auxin is also transported along the ventral side. Thus epinastic curvature appears to be due to the action of gravity, which causes the asymmetrical transport of auxin. This response is comparable to geotropism, except that the auxin accumulates on the morphologically determined upper side. The horizontal position of lateral branches is attained as an equilibrium position when the geotropic auxin distribution is equal and opposite to the plagiotropic distribution.

Nyctinasty. Nyctinastic movements are those induced by changes in temperature and illumination. This combination of stimuli, both of which are more intense during the daytime, causes some flowers to open in the morning and close again at night. The "sleep" movements of certain leaves are generally included in this category. Most likely, such movements of flowers are caused by unequal growth rates on opposite sides of the petal, but the movements of leaves are dependent on changes of turgor (water pressure) in the pulvini (enlarged areas at the base of some kinds of leaves and leaflets). Frequently it is difficult to determine which form of energy is the primary stimulus, but in some instances the individual causative factor can be implicated. For example, before the petals of crocus or tulip are completely expanded (mature), they will open when illuminated and close again when darkened, even when kept at constant temperature. This type of response is defined as photonastic curvature. Similarly, at constant light intensity these petals will manifest thermonasty; that is, they will open in warm air and close in cold air.

Haptonasty. The movement of marginal tentacles of the leaves of sundew plants in response to contact by an insect are known as haptonastic curvatures (*see* INSECTIVOROUS PLANTS). The insect is thereby brought into contact with the smaller central tentacles and ultimately trapped. Similarly, in the Venus flytrap, contact stimulation causes the leaf blade to fold at about the midrib and to come together to trap the insect. Haptonastic movements are also shown by stamens of some species in the plant families Berberidaceae and Compositae and by stigmas of the genera *Mimulus* and *Strobilanthes*.

Tactic movements. Movements of motile organisms and free parts of nonmotile plants in response to external stimuli are called tactic movements.

Phototaxis. These are oriented responses of such plants or plant parts as gametes, spores, algae, and fungi to stimulation by directional illumination (phototactic movements). Generally these forms swim by the use of their flagella and move toward light of low intensity (*see* ALGAE; FUNGI). This is positive phototaxis. When the light intensity is very high, however, the movement frequently is directed away from the light (negative phototaxis). The plasmodia of slime molds (Myxomycetes) move away from light by means of their pseudopodic action. *See* MYXOMYCETES.

Flower fruit and seed The wer rs ft n m p ted a mod fied hoot b aring ll ral org t d of le Thes gans a th epal pet s t m and c rp l The p l and pet l are le l fl k appe d g Sep l lk lea s r mm nl green Pet ls o t r l ttle lo ophyll e lly white h me olor he th g ee Th p l e llecti ely t t t e caly the petals the co ll Th l a d co ll f rm the peria th r fl ral en elope The st and c rp l a th r p od t fl ral organ d p d x cell A tamen is u u lly m o d f a l de t lk called the filament at the p f h h an a th Th th d ded to f ur fe e p lle acs in which pollen a d l p Whe m ture the pollen sa pe d th p llen t t ferred by w d w t n ects, m to th tip f th rpel a proc s alled p ll t o Th mbl e f tam lled th d o m t rm imply ng the male t t f th part f th fl wer Th a pel a em bl ge lled the gy ec m to i d c te it f m l at P til a the t rm ed t design t the f m le part of the fl A si gle c rpel m y f rm a p til tw or m r may be coml d i t a mp d p t l Th p t l ge lly o s ts f n enl ged b l p rt lled th ry The ap f th ry lly n ws i t t lk called the tyl th t t rm t a ticky u fa the t gma. Th ary t m l The egg c ll p oduced h l b mes f t l ed by th p rm b ght t the l by th poll n tube Th l tt tg th f a p ll gra th t be m atta h d t a d g rm ted th t gm Th polle t b g ow th gh the tyle t th l h e t d h ge th perm Aft th gg i f rt lized by p rm th ry m t me tog th with oth fl l p t d el ps to fr t Th le be me ed

Se p t rt l f d t led d of th ar pla t g Se PLANT PHYSIOLOGY PLANT TISSUE SYSTEMS [K E]

Bibliog phy P ANT ANATO Y

Plant physiology

Th b h f bot y wh h mpr es k wl dge f th p oc e wh h c pl t It f d m t l te t of phy logy e e th t th u lly mpl p oc es c rr g i l ving or g m n be l ed nt the el tı ly mpl p oces es f phy cs d h m try The fi ld f pl t phy logy th ef r g d mpe pt bly t th fi ld f pl t b o hem try a d pl t bio- phy M h p g es n l d t g th d t l d mech m f th phy l g c l p c th t o in pl nt h b ch d by u g phy c l d h m l meth d to l f perm t t o pt h bee f d in wh h pla t p oces es d t p te r d e w th th f d m tal p pl of phy d h m t y All p oc s s r g n pl t a e bj t t th d l nt l f th g t f ct r h ent w th th pl t d the e m t l f t rs t wh h it s ubje ted The t dy f tl e effect of en ir nmental f t r u n phy i l gical proces es theref re ft mes with n the purview f plant phy l gy l thi area of knowledge plant phy i l gy rlap with th feld of plant ec l gy i a bord rline d main f k wledge which i ft n called phy l g al l gy

Th effe t f g t fa t r i p the phy i logy of pla ts are under implied c n i lerati n wl never the same proce s i t died c mparati ely f r tw d ff nt pec e of pla t r e en d fferent a ie ties of the am p D ffe en es in phy l gy between pecies are as m h r flect n f th ir gen t d ff ces a are th ir m r l d ffe e ces in ext rn l m ph l gy Genetic d ff r e phy l gy are ft n much m re i l tle than m rph l gi l d fferences var t e f the am spec e indi t h ble m rph l g c lly r nearly s ft d ffer t a m ked degree tl phy ol gy

In e t g t ns f the mechani m whereby p f e ge t c fact rs—the ge es f the h m some—i fluence physiolog al proces es in l p eci p b g i t th metabol pathway withi ll and to th patt r f e zym tic ct ity which t ol h pathway Th s subd i ion f bi l gy ofte called phy l gi al genet N h rp b dary be d awn h we h tween th s realm of k wledg d the realm of pla t pl y l gy

A i t m te r l ti ext ts between the cell lar tur f a pl nt d the proce whi h oc r i t Th el t o h p i a d l The org ns a d ti ues f a plant tig at a r lt f gr wth wh h i t elf c mpl f oord n ted phy l gi l p e es O ce mat al ed h w e r the ga zati f a ll th ll lar truct e f a g e t s o g m y h m ked eff ts n th m n r n wh h e ti u g phys l g l p ce es p o ed w th n t Process a d tr ct e a n pa ble fac t f the phe m e n f g wth n pl nt S PHOTO YNTHESI P ANT MINERAL NUTRITION OF PLANT WATER RE LA IONS OF PLA T GROWTH PLA T HORMO ES PLANT MET OLIS I PLA T RESPIRATION [B S M]

Plant respiration

A ch mi l p o ess whe eby l g p t pl m k d wn ta o g ubst e w th the r l f gy wh l sed o s m tab l c t it es In nt a t t ph t y the s wh l ght (d t) e gy i h ged t h m l gy th t b d i gan c m l l r p t co t f a s f tr t n n wh h a ll t o ll f th h und en rgy le s d f n g c m l l F mple s gr d lly l ke d wn a e f r a t wh h l th le f e gy d wh ch m y ult m t ly lt th f mat n f c b d x d (CO_2) d w te (H_2O) S PHOTOSYNTHESIS F r th t t ll taly t ll d zyme m t b p e t t s rv tw f ld pu p F t th y t m t l n spl tt g th

times to indicate a species precisely several adjectives were necessary and thus the name of the plant became a long and cumber ome descriptive phrase For greater convenience later writers attempted to shorten these names Finally in 1753 Carolus Linnaeus in his celebrated *Species plantarum* established the practice of binomial nomenclature—the use of only one descriptive word with the Latin name This usage proved so con enient that it was at once adopted by botanists Therefore the date 1753 is regarded as the beginning of our modern system of taxonomic nomenclature A binomial is thus composed of the noun or name of the genus followed by a word designating the particular species The generic name is always pelled with a capital letter most specific words (by some botanists all specific word) are spelled with small letters for example *Quercus alba* white oak

The generic name as noted above in many ca es was the exact name of the plant u ed by the ancient Romans The vast majority of members of the plant kingdom were of course out ide the bounds of the ancient world and not being known to the Romans had no Latin names To gi e the system universal application Latinized generic names for such plants had to be invented Such names as *Fuchsia* in honor of Leonhart Fuchs a di tinguished botanist originated in this way

Authority for plant names It is customary to indicate the name of the botanist who first applied a particular scientific name to a given plant This botanist is said to be the author and his name (often abbreviated for convenience) is placed after the scientific name of the plant or group this is the citation An example is *Trillium e ectum* L. a plant named by Carolus Linnaeus The better known the author the horter is the abbreviation of his name Linnaeus a name wh ch is very familiar i abbreviated to L but few others can be o greatly shortened

International botanical congresses As the exploration of the earth s surface was extended thou ands of new plants were di covered and gi en cientific names In the applicati n of the e names discrepancies in practice became apparent Per onal and national jealou ies complicated the situation and the need for an international accord became ident The Fir t International Botanical Congress called l y the Swi s b tani t Alphonse de Candolle convened in Paris in 1867 Other con gre es were held at Vienna (1905) Brus els (1910) Ithaca N Y (1926) Caml ridge E gland (1930) Am terdam (1935) Stockholm (1950) Paris (1954) and Montreal Canada (1959) These congre ses ha e re ulted in the codification of the International Rules of B tanical N menclature

International rules of botanical nomenclature These rule go ern the application of cientific name under arying situation For example no plant hould ha e m re than one cientific name I ould more than one by error ha e been applied the earlie t in general has priority all others are ynonym Likewi e two plants can ot ha e the same name If the same name has been applied to two or more plants the duplicate names are called homonym and the later homonym mu t be replaced by a new name Where a plant i fir t described in one genus and later tran ferred to another the original epithet mu t be retained unless the same epithet already exi ts in the new genu If a conflict such as this develops a new name must be adopted The e are only a few of a very large number of items covered by the International Rules In each new congre s the rule become m re complicated *See* PLANT CLASSIFICATION PLANT KINGDOM [E.L.C.]

Bibliography *See* PLANT TAXONOMY

Plant organs

Plant parts having rather di tinct form tructure and function Organs however are interrelated through both evolution and development and are similar in many ways

Roots tems and leaves are vegetative or a exual plant organs They do not produce ex cells or play a direct role in sexual reproduction In many species nevertheless the e organs or part of them (cuttings) may produce new plants a exually (vegetative reproduction) Sex organs are formed during the reproductive stage of plant development In flowering plants sex cells are produced in certain floral organs The flower as a whole i ometimes called an organ although it is more appropriate to consider it an a sembla e of organ *See* REPRODUCTION PLANT

Root The root i usually the underground part of the plant axis It may con ist of a dominant primary seedling root (taproot) with ubordinate branch roots as in carrots and beets or it may be composed as in grasses of numerous branched root of similar dimensions (fibrou roots) Collecti ely all the roots of a plant are kno n a it root system Roots anchor the plant ab orb water and mineral alts in olution from the il and onduct the e to the stem Organic food and gro th substances received from the tem move to the area of growth and torage in the root

Stem and leaves The stem is u ually the aerial part of the plant axis and bears leave The tem and leaves together con titute the hoot In me pecies the major portion of the tem grows h ri zontally beneath the surface of the oil and th i called a rhizome or underground tem The tem c nducts water and mineral from the root to all p rt of the shoot and food materials and gr th s b tances fr m the shoot to the root The stem may al o erve as a storage organ for water and food Green leaves containing chlorophyll hen expo ed to light and air carry on photo ynthe i A a by product of thi proce oxygen i returned to the atmo phere Lea e al return large am unt of water vapor to the air through tran p rati n (evap rati n) Some leaflike tructure are protective (bud cales) others are fleshy t pes in wh ch f od and water may accumulate The fir t leave on a seed plant are led n

ult i the r g e at on of the 4-carb n c mpound l tate The cycle is then repeated by adding an th r m lecule of p ru te D ng the cy l in add t n to the CO formed m of the i ter medi t e mp u d are o idi ed by the removal of hyd e The hydr g n may rea t w th oxygen l y m a of c rta n enzym y tem t f rm H O

All th mole le f pyru ate that re ult fr m gly oly s a e not decarbo ylat d a d ox di ed to CO_2 a d H_2O S m of the pyr ate m lecul s may (1) p rti ipate n the format o f h gh pho phat bond en rgy e zymes (2) i nt rmed te c m p d amin a ids sy the (3) b precur r via a etyl c enzym A f r the synthe of fatty ac ds d (4) be ther p ec rso fo the b o- synthes f im l tion p d cts.

Unle om of the pyru ate m lecules a e tili ed i th ab m nt oned metabol c path w ys, the integ ated m tabol m that i the ba s for l f wo ld cea A fa a i kn wn this h lds true f most l ll

Th f rmat of L malat fr m py u ate by the add i n of CO th t i a comp nied by the o id za ti n of TPNH i k wn a arbon d o d fi at n o carboxylat o Th s m ch nism is im'l r to but d tinct from CO fi at on in ph tosynthe The p l d ff ren appe rs t b th spe ifi k d of orga molec l th t acts a the CO_2 accept r A obic resp at can be s mmari ed n it en t eact ons f llow

Glu o e
(1 mol cule)

$\downarrow$ Phos h rylases

Fructo d pho ph te
(1 m lecul)

$\downarrow$

2 Pho ph lyce a d $\xrightarrow{\text{D hydro ase}}$ 4H + Ca a $\xrightarrow{\text{Oxidase}}$ O_2
(2 molecul)

$\downarrow$ 2H O

Pyru ic a id $\xrightarrow{\text{D h dro enase}}$ 20H + Carr $\xrightarrow{\text{dase}}$ O
(2 m lecule)

6H_2O $\rightarrow$

$\downarrow$ 10H_2O

6CO

Energy transfer In the b s i f rea t th r p r t y p o s s g b k d w b m n f st p by tep d t on re lti g n l s f rgy at ch t p S m of th ergy i d s- ipated f e mple h t en gy M e m po i nt, h weve the e gy wh ch s tr fe d t the ph ph i zym a d wh h i bs q tly l d n n b y the e wh h th sou f gy f r th se r a t s Th t f f g i h w n th p e ly d s u d r t n be h n rgy t f l dd t n l t

Th k y ph ph te e zyme a the tw ade der t Th ad n e d ti re mole ule comp ed f ad e r bo e nd ph ph t g up The pho phate g oup c ntain the stored energy Ade o ine i pr duced from the rea ti n of ril e nd de ine Aden n d pl spl ate (ADP) has two pho phate group , wherea ad n inetriph spl ate (ATP) h three gr up Each ph pl ate gr up has 12 000 calo es of energy per m le It is only re ently that the m chani m of the adeno ine f r mation ha l en und r to d in its relati n hip t r sp ration F r e ample d ring gl c ly i ADP and ATP a f r ed when ph ph glyceraldehyde is c n erted to 3-ph phoglyceric ac d This may b sl own a f ll ws

3 Ph phoglyceral lehy le

$\downarrow$ Phos h te

1 3 Dipho pl glyceraldehyde

$\downarrow$

1 3 Diphosphoglyceric acid

$\xrightarrow{\text{E gy}}$ Ad—Ph~Ph (ADP)

$\xrightarrow{\text{transf}}$ Ad—Ph~Pl ~Ph (ATP)

3 Ph phoglyceric ac d

The above transfer of energy rich pho phate bond (Ph~Ph) can acc unt for nly a small por tion of th en rgy which is stored as such b nd Research has hown that the complete oxidat on of 1 mole of he o e to CO and H O hould relea e 680 000 c l Actual mea urements sh w that ap- p o imately 290 000 cal are not relea ed but are sto ed the form of phosphate bo d energy It is not ent r ly cle r how the remai ng energy is tra ferred t st rag b t it is thought that ATP e ated duri g the K eb ycle or pyru c a id x d tio B hem ts now are of the opinion that duri g the pl tt g ff of hydrogen a d ca bon di x d th e react ns inv l e th tak g up of ph phate and the f rm t n f organic pho ph te int rm diat wh ch in t rn lea the en rgy h ph sphate bond to ATP The t ansfer of ergy ca cc at ny f the teps in th Kr bs cycl and may be ill t t d at the pyruv c to ac t acid tep f ll ws

CH COCOOH + H_3PO + DPN $\rightarrow$

CH CO H PO + DPN H_2 + CO_2

Pyruv c d Ph phate Col $\rightarrow$

Ac tyl ph sphat Red ced Col

$\downarrow$

Ac t c d + Ad—Ph~Ph~Ph (ATP)

A s mma y of th ct i gi en n T ble I w th the n mb r f pho phate h gh en rgy b nds y ld d Th 16 b nd y eld 184 000 cal o t of the

T bl I S mm ry f re ction i K cit l eld cy l

Rea t ns	N mbe f e gy h bo d
Pyr → Acet	4
Isoc tri → α K t gl t	3
K togl ta → S cin	4
S → F m r	2
M l → O l t	3
T tal	16

more complex organic molecules into simpler ones Second and perhaps more important these enzymes facilitate the transfer of energy to energy rich phosphate bonds *in organic phosphate molecules See* ENZYME

Mechanism of respiration For an understanding of the many integrated reactions in respiration it is first necessary to establish that the living cells of ome species of plants have respiratory reactions which do not require utilization of free oxygen An example of uch a species is yeast in which the following respiratory reaction occur

$$C_6H_1 O_6 \rightarrow 2C H_5OH + 2CO_2$$

The end products of this anaerobic reaction are ethyl alcohol and carbon dioxide whereas in the utilization of free oxygen in respiration carbon dioxide and water are the end products (*see* PLANT FERMENTATION) Many living cells have both aerobic and anaerobic respiratory systems Consequently the kind of respiratory reaction that occurs is generally dependent on whether free oxygen is pre ent Some species of bacteria cannot live in the presence of free oxygen and are known as obligate anaerobes In both aerobic and anaerobic re piration the end products are formed only after a number of intermediate reactions The intermediate reactions common to both aerobic and anaerobic respiration are called glycolysis and do not utilize or require free oxygen *See* BACTERIAL METABOLISM

Glycolysis The central feature of the initial breakdown by glycolysis is the conversion of hexo e ugar to pyruvic acid through a eries of reactions which involve phosphorylated deri ati es of hexo e sugar or other carbohydrates Each step involves *the action of a specific phosphoryla e enzyme the teps may be summarized as follows (enzyme* names are shown be ide the arrows)

Glucose
↓H k ase + ATP
Glucose 6 phosphate + ADP
↓Phosph h m as
Fructose 6 phosphate
↓Phosph h k ase + ATP
Fructose 1 6 diphosphate + ADP
↓Ald l
3 Phospho lyceraldel yde + Dihydroxyacetone phosphate
↓Triosephosph te d hydrog se + DPN
3 Phospho lyceric acid + DPN H_2
↓Phosph gly rom tase
2 Phospho lyceric acid
↓E lase
Phosphoenolpyruvic acid + H_2O
↓Phosph t nsf rase + ADP
Pyruvic acid + ATP

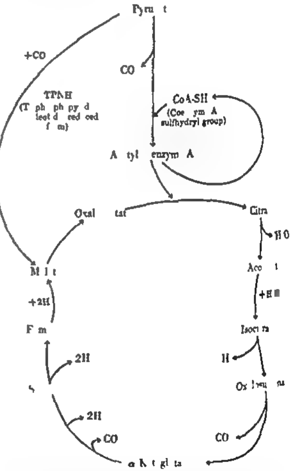
With the formation of pyruvic acid the initial *and intermediate* teps common to aerol ic and anaerobic re piration end The fate of pyruvic acid is different in the two kinds of respiration In one type of anaerobic re piration the following reactions occur

$$\text{Pyruvic acid} \xrightarrow{\text{C bo yl}} \text{Acetaldehyde} + CO_2$$

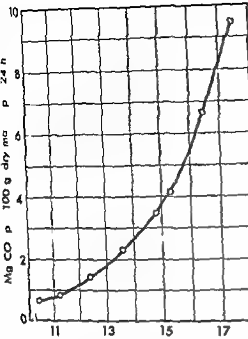
$$\text{Acetaldehyde} + \text{DPN } H_2 \xrightarrow[\text{f}]{\text{Al h l d hydrog nase}} \text{Ethyl alcohol} + \text{DPN}$$

Krebs cycle In aerobic respiration pyruvic acid is converted to CO + H_2O by a eries of reacti n known collectively as the Krebs cycle This cycle involves two kinds of enzyme dehydrogena es which remove hydrogen and carboxyla es which remove CO The dehydrogena in turn rele e the hydrogen to the terminal oxida e which combine the hydrogen with free oxygen in *forming* H_2O Thus the end products of aerobic re piration (H O and CO) are the final products of pyru ic acid oxidation

The Krebs cycle may be summarized by the following steps



By the addition of the pyruvate (3-carbon compound) to oxaloacetate (4-carbon compound) and by passage through the Krebs cycle three molecule of CO_2 are split off from different intermediates and suff cient hydrogen tran ferred to oxygen to yield H O In the f rmation of citric acid (6 carb n compound) from oxal acetate plus p ru ate one molecule of CO is liberated The citric acid is then degraded via the Krebs cycle with the los of two additional mole of CO_2 Thi re-



Fg 1 Th oc t f th t f p to me sured by CO_2 l t w th th m t te t f yb e d (F m P E R mst d o d W F G d d Th R p t d St ge B h f S y b M Ag E p Sta T h B ll 156 1942)

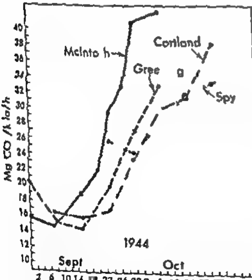


Fig 2 Th ff ct f g f fru t d t d by h w t d t f o th t f e p t m d by CO f t F se f t f ppl (F m R M Sm k d C R G C B U Ag E p S M m 297 1950)

r t tw t th t me f h 10 d g f cents g d) t mp t r Th t f f th p oc exp ed b th mb l Q nd lled th temp tu ffi nt Bet e 0 d 3 C th Q f m t k d f pl t t 2 0– 25 Abr e 3o C th r t f r n rat h

hown to i crea e f r h t period f time l ut f m 40 to 45 C the rate r pidly fall t le s tl an r t s at 30 C. Thi s thought to b due to en yme ina t vati n a d failt re to mai t in a upply of ubstrate At 35 C l we er tim e may affect the re pirato y inten ity of some ki d f plant rgan The eff of temperature and time n the rate of re pi ation of pl nts are grapl i ally p e nted in Fig 3

The n ide ati n relati e t factor affect ng re p atory int n ity are appl cal le to l th ae ol ic nd a erol c re pi at A pre i ly indic ted th rat of er l c respi n i affe ted l y th *con ntr t on f xyge* well a l y ther fa to s In clo ed chaml e ntaining plant material o whi h r pir t n i l e ng determined unless th o yg u ed i repla ed the a i t l e l aml er bec me pr gre i ely lower in o ygen and high r in ca l o d xide The rate of re piratio i de- cr ed und r such c d t on It i diffi ult to d termi fr m the d whether u h a decrea i th es lt of CO t xi ty r lack f O The dir ct effect f xygen c nce trat n can be determined nly under exper me tal co dit ons where oxyge is tl e r abl and CO *kept at tl e normal tm s* phe i le el L. L. Clayp ol a d F W Allen t idi d th ffe t f xygen c ntr ti n on pl m f uit re pirat n de uch exp imental d tio s d the data bta n d at 86 F are prese ted in Fig 4 The e d t h w that with increa ng o y g c n ent at fr m l t 50% a celer ted r tes f p t n w re obtai ed whi h maint ined a fa rly t t r te w th time At xygen concen tr ti ab v 50% respiratory inten ity s c el er t d fo h rt per od of time but tl n falls off

The d ect i h b t ry effect f i creasi g con tr t o of a bon dioxide on e p r t on h s be n d m n tr t d b g min t ng mu tard see l H we er i c ng CO conc ntrati n does not lw ys ha e a d e t nhibit g eff ct on re pira t n Le e in l ght pl c d h gh r nc ntra

Fg 3 Th ff ct f t mp t th at f p t o m d by CO lut f W k pl m (F m L L Cl yp l d F W All H la d

274 000 cal released by oxidation of pyruvic acid or an energy capture of 67%

In the preceding discu ion it ha been demon strated how energy i captured in re piration Now it becomes important to show how a respiratory intermediate product is synthesized into a cellular constituent This is the econd important function of respiration in terms of metabolism because CO H O and di sipated energy are u eless α Ketoglu taric acid a respiratory intermediate is the raw material from which the amino acid glutamic acid is synthesized This synthesis occurs as follows

$$\alpha\ \text{Ketoglutaric acid} + NH_3 \xrightarrow[\text{d hyd g ase}]{\text{DPN H} \\ \text{Gl tam}} \text{Glutamic acid} + H_2O + DPN$$

Factors affecting respiration From the previous discu i n on the nature of the re piratory mecha ni m it i evident that respiration invol es an extremely complicated eries of biochemical reac tions which are intimately related to all living proces es If this were not true methods used for the measurement of respiration would be far more accurate than they are at pre ent Respiration usually has been measured by the gas exchange technique In investigation of the rate of aerobic respiration as it is affected by a certain factor the oxygen u ed or carbon dioxide evolved is measured per weight of tissue The gas exchange technique thus operates on the assumption that respiration is a complete oxidation of sugar in which one hexose molecule is oxidized by ix O molecules and six CO molecules are released Hence the ratio of the volume of CO evolved to the volume of O u ed is equal to unity This ratio is called the respiratory quotient (CO /O) B t as the respira tory mechani m indicates every molecule of hexose sugar does not always end up as CO and H_2O Therefore the rate of re piration as measured by CO_2 evolution may be far from completely accurate as an index of the respiratory intensity However

Table 2 Rat s of resp ration of v o s plant spec

Spec es	Desc pt n	T m pe t C	I t ty of p t n ml O /(h) (g f esh wt)
C tu (C u)	H b eo pe l	1	3 00
E u d h ll	H b eo pe l	13	6 80
P kly pe (Op l)	H baceo pe n l	13	11 40
St rop	H b eo pe l	13	16 60
N w y spru	T ee	15	44 10
C mmon ow d p	P l b lb	13	77 60
B o d be n	H ba eou l	1	96 60
Fou -o lock	H baceo pere l	15	1 0 00
Wh t	An l	13	91 00

W St les, t *I trod ct t th P pl f Pl t Ph s log* M th 19 0

Table 3 Rates of respirat on of various plant organs

Spec es	T mpe t C	Respiratory nsity ml CO_2 /(h)(g f esh t): Sepal	P tal	Stam ns	Pi t l	Le ves
M ll	3 0	0 747	0 177	0 61	0 81	0 38
H l t gu	3 5	0 571	0 398	0 60	0 689	0 300
P ppy	0	0 390	0 36	1 041	0 690	0 332
T m ll w	0	0 615	0 303	0 5 6	0 894	0 394

F m W St l d W Le h *R p ral Plants* M thue 195

in the development of the pre ent knowledge of factors which affect the rate of respiration it wa necessary to evaluate respiration by gas exchange because better methods were not available to the investigators who obtained the data Such data do not therefore constitute an absolute indicator of respiratory intensity but rather indicate an ap proximation or what might be called an apparent re piration rate

The rate of respiration is influenced by a com plex of interrelated factors that is r piration intensity is dependent both on condition within the living cell and on environmental factors The role of the living cell in regulating re piratory intensity is illustrated by differences in rate of respiration between species of plant between organs of the ame species and by age of the organ Such differences are comparable only if environmental factors are the same These differ ences are substantiated by experimental data pre sented in Table 2 and 3 The e data how that at approximately equal temperatures re piratory in tensity varies with species of plant and with variou plant organs or parts of plant organs of the ame species

Concentration of substrate The di cu ion turn now to the que tion of why differences in re pira tion intensity occur Excluding environmental fac tors the answer i found in the intracellular fact rs which control the many reactions of respirati n These are concentration of ub trate uch as ugar concentration of enzymes enzyme acti ators and enzyme inhibitors and degree of cell hydrati n For example it has been hown that as ugar ub strates are exhausted the rate of re pirati n de creases (as mea ured by CO e ol ition) Like i e decrea ing cellular water content in oybean eed results in a reduced rate of re pirati n (Fig 1)

Tim factor Re earch on fruit ha demon trated that time i an imp rtant factor in re pirat ry in tensity The time effect as related to age of fr it i illustrated by the data on e eral arieties f apples (Fig 2) The e data how tl at a the apples reach maturity tl e rate of re piration i increa ed Other data how tl at this peak of re pirat ry in ten ity (climacteric) d e n t continue l t rap ll fall off to a teady tate

Enviro ment l factors The major envir nmental fa t rs which ffe t the rat of respirati n are temperature oxygen concentrati n carbon di id concentrati n and light Re p rati n is a chemi al reaction and thu temp r increa th

a e low ı hyd ph l c ollo d (o l eed) The m p ples are al appli abl to the torage f h r ps

I the di ı si n f temperature eff cts n the t f e pi atio th interr lati n hip betw en ph to synth s and e piratı as infl enc d by tempe re w s me t oned This ı terr lati h p s imp rt t n p yield The l ght nte ty at h h the rat f re p rati n nd phot synth e ar qu l lled the ompen ati n p nt If l ght int t a e uff e t t in ph tosynthe s at a rapidly as re in temp rature c u e c el r t n resp rat on the omp ns tı point ba es How b fo owth c n ccu in pla t p rt s ch tem ot b lbs fruit nd eed th ate f phot synth ı must e ed th rate of p at so that s ff t sugar r ma s f r le f p rat t n ht d f r tra l cation t storag g n Th tw on de at ons are ı ol ed (1) amo t f sugar n t ed n l ght and (2) r te of n ght pirat n which is ge ally c t ll d by ght temperatu es A well kn wn e ample ıl lu t at the e c ıde tions h s to do with the ize of I h pot t t b rs u d d ff ent cond b *Wa m ni ht* by cau ng a ompa ati ely high rat f e p t n lea e to l ttle ugar f r *wth of the t b* and m ll potatoe r ult O th *tle h* d c l n ght fac l tat yı ld of large pot toe *Th s* pe hab tats ıght t mper t re e ery mp rt nt ı *the growth* nd de el pment f ag gan *S* PLANT GROWTH PLANT MET BOLISM [J F F]

B bliog aphy J B nne *Pla t B och mistry* 19 0 J F F ry d H S W d *F d m tals of Pl nt Phy ol gy* 1959 D R Godd rd nd J D M u e Re p rati n f h ghe pl nt *A n R Pl t Phys l* 1 207 232 1950 B S Meyer a d D B A d n *Pl t Phy ı logy* 2d ed 1952 W St l d W Le ch *R sp t n Pla ts* 3d ed 19

Plant societies

A mblag f pla ts wh h n t tut tr t ral rt f pl t omm t They may be ompo- ts pat l r g ment u h as l y l fe f rm gr p lly o loc lly pr m n t pop l ti f pl nt *The e* ı g eme t s t the p s ge f th t rm be o d th g lly pted t that t hould be d f t tur l g t t n l m t f a k b l w w th the pl nt mm ty *wh le A h* r hy of p o- g es iv ly l g u ts ı g t t n tr t r with a ex mpl s s follows

I di d al pl t → l mp f sim lar d d al →
(rose) (l f rose b hes)

s ci ty → c mm ty →
(hrub socie (oak h k ry
in l ding roses) fores comm nity
associa on)

om → b o h e
(broadleaf winte (f res b och re
dec d all f es f rm ns)
f rest b m
orld pl
f rm
associated an mals)

Soc et es can be defined on the bas of structure d m nance sea on and l fe f rm

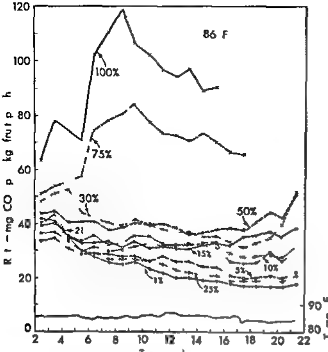
Structural societies The e ocieties are groups of plant within a c mmunity wh h attain appr x imat ly the ame h igl t and wl icl l ear their f li age at about the ame le el abo e g und They are also k own a layer oc et es r uni ns Such cie- ties may form a more r le s c nt nu us layer thro ghout the area ccup ed l y the commu ity In a f re t for example the e is tl e can py society of tall t ee low tree c ety shrub so iety herb so- c ety a d gr und layer ociety These may l e r fined furthe if neces ary Some autl rs ha im pl ed o stated that ther c rtain c l ı n amo g the comp nent spec es of a lay r c ety gi ng it the status of a comm nity within a om mun ty Howe er sin e tl e e ı also often a tr ng int rd pendence b tween member of different l yer so iet es as in the influence of th canopy upon the den ity of lower vegetat on in a forest s ch oc eti hould not b regarded as indepe d ent ent tie A us ful et f symbols for the rec rd ı g f spatial a rangement of vegetatio has been p posed by P Dansereau

Dominance societies Th e societies have been d fined by J W a er and F Clements a aspect o- ciet e r ser e of tand cl arly bel g ng to a c t in mmunity In ad l tion to the cl ar cter tic d m n nt thes so etie pos es ce tain ub- d m ants r c domi ants of another l fe f rm r a pe t than the dom ant elements f the c mmu n ty The c cept is u eful e peci lly in gra lands ma he heaths nd the egetation types in wh ch d m ce an im o t nt feature *For in* t nce prair e omm nit e may be defi ed n the b f gra s pecie With n thes communitie erta n spic o s b adl ed h bs form l al pect eties The extent nd d l pment f h so et es ha e be n sed a ind c t r f the ecent h story of gras la d stand especi lly with gard t limat fluct ons

Seasonal societies Wea e nd Clements also appl ed the te m ociety more p eci ely to gr ups of plants wh h det rm e the e o al a p cts f pl nt c mm n t e Examples of such so al o- t es th rpet of trill m *bloodro t*, d g ı the p ı g the aste s nd g ld r d of ban d ned p t s n lat summer a d th m ses of sho t l ed l wh h s ddenly d v l p fter pr ng r th w t rn des rt Su h et e t u tu al un ts by rtu of th n f *m tim* g f phe l g s f the pl nt pe n l ed

W thi mm n ty th r may be a p og si n f s asonal c t s e al → v l → st al → e t n l → aut mn l → h nal E ch o- c ety m ke t own demand p n th r c s of th l ab t t Th ef f ll u d r ta d g f a mmunity q ob erv t n f ll ts l a pects

Life form societies Pl ts in mmu ity wh h h th ı m nt



Fg 4 The effect of oxygen conc nt at on on the rate of re p ration as measured by CO e olut on of W ck son pl m (F om L L Claypool a d F W Alle H I gard a 21(6) 129–160 1951)

tions of CO_2 have higher rates of respiration because the increased photosynthetic rate results in more sugar substrate for respiration

Food production and food use When food production is compared to food use the maximum rate of photosynthesis occurs at lower temperatures than the maximum rate of respiration (Fig 5) This means that during extremely hot daylight hours of summer the rate at which food is made by photosynthesis may barely equal the rate at which food is used in respiration Respiration goes on continuously day and night and photosynthe is occurs only during the hours of daylight thus it is evident that if such conditi ns per i ted for a ery long period u e (respiratory decomposition) would greatly exceed the production of food growth would cea e and the plant would succumb

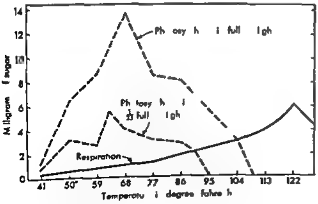
Respiration and agriculture Data from respira tory re earch have enabled scienti ts to recommend methods whereby various food products may be transported and stored with a minimum lo s of quality Fruit and vegetables are kept at high quality for shipment and storage by refrigerati n. The reason for refrigeration is that low tempera ture causes respiration rate to be at a minimum Deterioration in quality occurs at the higher tem peratures because of factors as ociated with high rates of respiration Deterioration i also held to a minimum by the maintenance of high CO con centrations and low oxygen concentrations in tor age structures but refrigeration is the mo t widely u ed method

Unlike fruits and vegetables seeds which are to be stored for food or planting purpo es can be kept at high germinability with little deterioration by removal of moisture from the seeds to a level where the rate of respiration is at a minimum Maintenance of germinability with prevention of lo s in quality of stored seeds is now being carried out on a large cale by removal of moisture from eeds to a moisture content which is afe for storage Moi ture removal is accomplished either by natural curing in environments of high evaporation or by artificial drying in humid environments The afe storage moi ture contents of several kinds of eeds are hown in Table 4 A considerable variation exists in safe storage moisture contents among the different kinds of seed becau e safe torage moi ture content for a seed is the moisture content which will be in equilibrium with relative humidi ties of le s than 75% so as to prevent or check microbial deterioration The equilibrium moi ture of a particular kind of eed at relative humid ties of less than 75% will depend upon the chemi al constituents of the seed Seeds high in hydrophil c coll oid (proteins and tarches) will ha e higher afe storage moisture contents than eeds which

Table 4 Safe storage mo stu e contents of various ki ds f seeds for maintena ce of high g rminabil ty a d low d terioration

K d of eed	S f t ge m t re co t nt *
B l y	1 0
B kwh t	1 5
Bl l p	11 0†
C n	1 0
C mso l r	10 0†
Fl eed	7 9
O t	11 8
P t	6 0†
R ce	1 5
Ry	1
S *l ped*	8 5†
So gh m	11 9
Soybe	9 3
W t m l	8 4†
Wh t	1 0

O l of w t w gl t
† D t rm ed l y Ag cult l E pe m t Stat n, Al bam I lytech I t t t



Fg 5 R l t e rate of photosynthes s a d p a to n potato le s d r g 10-m te po e to d ffe e t t mp at r s i shade a d f ll s l ght R calcul t d from data by H S Lu d ga dh (From E N Tr n a H C Samp o a d L H Tffa y T t b ok of Botany Harp r 1953)

taxonomic literature

my b c lly des ripti e and its l te a lumin us It is fo nd i all rt f p ibli f om l rg l m t m ll p mphlet gl ks to a t l p ri d al T f i mpl cat th s tu ti every nat on h s had m t and th l te t h s ppe ed i l gu ges The ef g at d pe de ce m t ed p g fi nt i dex t t n m fl ra and e l wo ks of a br ad

exes O f th m t helpful i de e i t nom l t at p o de refe c t fi am f ed plants Th s i tl e I dex is pl t um ph e g m rum i p red m d fi ally p ble by a gift f m Darwin t the Kew Bot l G de d The o g al w k p bl hed i 1893– ted f lphabet al l t f gene a h d f m 1753 the d te f C r l Li Sp ci pl t m (see PLANT NAMES) it 1885 U de h ge e me was g en ph betical o de e ry p fic p thet k wn bee p bl hed that u ach entry f ll ed by the n m f the tho the place bl tio a d the n t u t y f th pl nt en ppleme t w e p bl hed p t 1953 d k h b ome a d pe ble fe en ll pl tt m t

Other indexes G ph m m p b- d B l 1907 l t by C G Dalla d H H m wh h g d f m l es g a f seed pl t ged sy t m t lly mb ed e ut ly from 1 t 9629 Th m ri d the mb re d by som c t a a ba s f fil g he b r im te l (HERBARIUM) Th lt t b t c nd d t n par d by C A P t l Le pzig 1872 g a t f mp t t t tl f b tan c l wo k p t the te f ts p bl cati

General works of a broad scope No s ngl k t t f every pl t pe e one th N m t b t h we d l w th g fi t gme t f th pl t k gd m S m f th a e P d mus yst m tis i l g g t b l l m d 4 d l m s P i 1824–1873 h k tt mpt t nt f ll p f tyled Th fi t eve l m we w tten A gu t Py m d Ca dolle th m d ed ted by h Alph d w itten by om th rty fi e m g phe l d g Ca m Ca d ll s n f Alph e D A t l h Pfl f m l A E gl d Pa tl d t Le p g 1887–1915 A 23 l m k l d g k y d c pt d ll t t f m les d g f ll pl t e pt b te S mm rie r g e f f rm t rn ng mbry l gy m ph l a t my t my d p leobot y f h w th f e t selected b bl g phy

Das Pfl zenre ch Leipzig 1900—— A work f o r 100 lume beg n by A Engler deal with g nera and pec es of a cular plant of the world

Floras A de ripti e ma u l r flora is a y temat t eatme t f the pec es of a gi en area w th de tifi ati n key nd de cr pt ns of tl e wild plants f the reg n (s e PLANT KEYS) There are refere ce w rks ng in d ta l all plant k own t e t t even if ch refer w rk were a lable they w ld be too c ml r me f r di n ry e Regi al fl a h we er make a ailable the det ils f the plant life of th w rld region by region

In s me p rt of the w ld l cal vegetation ha been tud ed c ref lly fo ma y y ars and few if a y new pe ie are l k ly t le f nd But in ma y the reg s manual are e th r u ava lable r a e a t q ated o inc mpl te a t l e of little al e Thi e pec lly t ue f Africa A a a d S th Ame ica but om pa ts f Eu pe North Am rica and Au tral st ll lack ca efully p e- p red flora

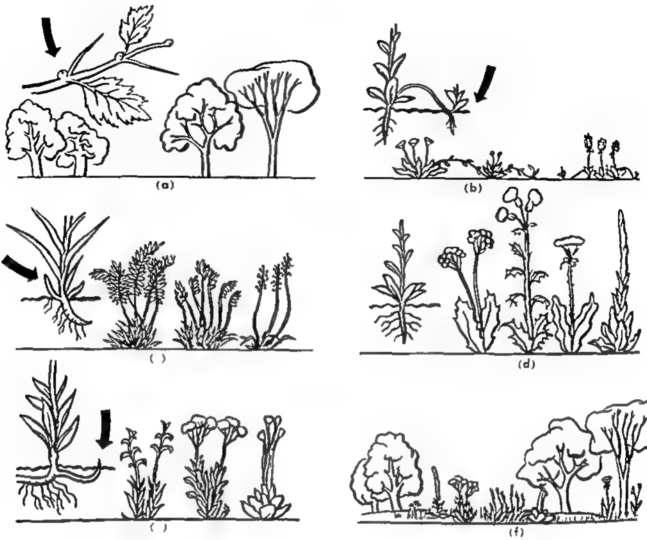
M st parts f the Un ted St tes re c ered by g o al m nual F r th n thea t rn tate G y s Ma u l of B t y h s l ee the standa d ref ere wo k for ent ry Th 8th ed ti ed ted by M L Fe ld app ared 1950 An ther n rth tern fl is N L B tt n d A B wn Illu t t d Flo a 3- l me w rk th third d tion by H A Glea n appeared in 1952 F r the uth a te tates th pri pal w k i J K Sm ll M u l f th S the st Flo p blished 1933 The m t ext e fl f the c t al tates P A Rydb rg s Fl f the P tes a d Pl ns p bl hed 1932 Fo th Rocky M ta region th m t e te fl ra s Rydl erg s Fl f th R ky Mou t ns d Adj e t Pl i s the 2d ed t pp a ed i 19 2 The P c fic t te a e c e ed by c mp h work A Illu t ted Flo a of th P cific St t by L. Abr m a d others the w k w ll include 4 l m p bl hed n 1923 1944 a d 1951 w th the fi l l m t ll n prepa t

Fo outh t n Ca d the t ndard w k is Ma V t Fl lau t e e publ hed in 1935 S PL NT C SSIFICATION PLANT KINGDOM [E.L.C.]

B bl g phy S PLANT TAXONOMY

Plant taxonomy

The y temat c l ati nd ngem t f pl Pl t t x my req e owl dg of t g l n pts h as p c es g nu d f m ly f th rul f b th rt fi l a d nat l system of l fi t d f nt t l rul s f n m l tu c t all g pe fi lly the g n d u of a gle a d n lly ecogn ed sci e t fic m It al cl d th mak g a d e f pl t m l k y d th cl s fi t n p ed es t gethe w th the mpl yme t of ap p ed m thod f c ll t g sy tem t c lly d g d p e erv g pl t p c me T n



A lys of a hawtho n abapple comm ty in term of l f forms (w th s a onal o lat o) W th e ch s c ety a d ag m the l ft shows o e w te g t uct e (rrow p t ng t bud) (a) Soc ety of low dec d ous t (b) Society of sod fo m ng g m no ds (c) Soc ty of rosette form ng hem cryptophyte (d) Society of tolon fe o s hamaephyt (e) Soc ety of o ette b e als (f) St uct e of th nt re comm ty

buds at the same le el in or ab ve the oil constitute life form societies or synusiae Members of such societie are therefore subject to similar growth conditions and frequently de elop accord ing to a imilar pattern The illustration shows how a plant community may be analyzed tru turally using life forms as a criterion to distinguish societies such as the following (1) society of clumped low deciduous trees (hawthorn) (2) society of sod forming graminoids flowering in midsummer (bli egra s redtop and o forth) (3) society of short rhizomatou hemicryptophytes with winter m ettes and autumnal flowering period (g lden rod a ter) (4) stoloniter us chamaephytes with winter rosette flowering in early summer (pu sy toes cinquefoil trawberry) and (5) s ciety of biennial ro ette plants (wild carrot thi tle mul len)

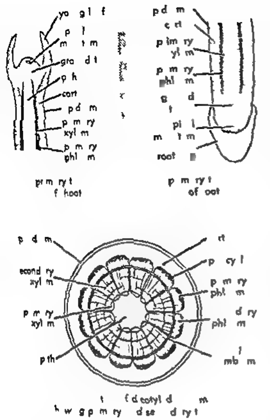
Such divi ions into cieties are u eful becau e they demon trate the arrangement in pace of the aerial and underground parts of the pecies in the community a well a the timing of the r vegetati e and reproductive cycles

From the enumeration of criteria it is evident (1) that all types of societies regardle s of the criteria u ed to define them have certain common features and (2) that there is a lack of agreement regarding the preci e meaning and definition of the term society Pending a definiti e international acceptable ocabulary f r ecology the word society hould be used only with a qualifying adjecti as seasonal society or structural ociety Wher another term with a more specific meaning is a ailable as union for structural ociety or synu ia for life form society the word should be avoided

The society concept remain u eful to ecol gi t in the analysis of vegetation as a general term f r tructural elements *See* PLANT COMMUNITY

[K LE]

Bibliography S A Cain and G M de Ol eira Castro *Manual of Vegetation Analysis* 1959 J R Carpenter *An Ecological Glossary* 1956 J E Wea er *North Ame ican Prai ie* 1954 J E Weaver and F E Clements *Pla t Ecology* 2d ed 1938



P ory d d ry pl t t y t m

and oot, th a c l t s ues d me a soci ted grou d us ft tr ated a a t th stel C o d u may be pres t in the c nte f th tel (p th) d on ts p ph ry (p y l) The gr u d t e y tem cl s g the t le on the ut s de the rt It m y ha hypode m s pe ph er lly nd e dod rm n xt t the st le

The sec nd ry ti es a from l te al mer tems, nd the f rmat ma ly respo sible for the gr wth in th ck s of st ms and ro ts Th y mpr e ndary ular tis u nd the prot t ti alled p d m S o da y gr wth m y b ld up a m e c f wo d but the t ti y t m the k a k r m s el t ely th b c it ut r part bec m m p ed and, n m ny speci nt nu ly l shed ff

Th p od ct o of fl w r t d f eg t t v hoot es fr m phys log c l d m ph l g t l cha ge the p c l me istem whi h th be c mes the flow r m i tem Th l tt r how p od es t s) tems fu d m nt lly mila t th n th getat body f th plant See epa r t rt cles f d ta l d d s n of the a ou pla t t s s st m [K E]

B bl g phy S e PLANT ANATOMY

Plant translocation (organic solutes)

Th t ph f pla t met b lism t l ng th t a s port f ga omp u d th ugh th l t es (PHLOE ; XYLEM) f the pla t d tances of considerable magnitude relati e to the size of the plant for example from leaves to roots See LEAF (BOTANY) ROOT (BOTANY) In arborescent (treelike) species translocation distances often exceed 100 ft

Larg quant ties of organic solutes are translocated in plants For example in a single apple tree under fa orable conditions about 150 kg of organic solutes is translocated to the fruit during the c u se of th g owing s ason See FRUIT (BOTANY) In addit on large quantities are translocated from the lea es to the growi g sh ot tips and roots a well as sign ficant quantit es fr m the roots t the stems and leaves Se MERISTEM APICAL STEM (BOTANY) Acc rd ngly many of the deta ls of the t anslocation proces entail problems of significant cern t pla t phy i l g sts and agr culturi ts fr m both theoreti al and p actical viewpoi ts

Importance of conductive tissues The relati e mp ta ce f phlo m and xylem tissues as conduct ing elem ts in rganic transl cation varies with the d ffe ent kinds of ga ic compounds and m re significantly with the site of or gin r synthe of the compou ds in the pla ts Quant tati ely the most imp rtant compou ds tran located pla ts a e su rose a d certa n closely related olig ac cha ides p i c pally raffin (see OLIGOSAC HA RIDE) S ch ompounds are t an l c ted pred mi nantly in the phl em both bas pet lly nd r p tally th t is in the d ct n of the root d shoot t ps re pect ely Du ng tran loc t on n the tems a ns derable f act n of the sugar in t ans t may move rad ally from the phloem into the rt xyl m r oth r st m t es d a c mu l te t ch r oth c nden ed polymer par t cul ly i the ay cells a d in parenchymato s ella mm d ately adja ent t th trach e the ma n wat ondu ting ls (see PLANT TISSUE SYSTE IS POLYMER)

D pite the pr imity of th carl hyd ate re erv to the act e w ter c ndu ting cells i th xylem nly negl g bl q antit e f sugars appear the s p ext t d f m the t heal element d r g a maj tion f the g w ng sea on Al o n mer us r g ng perim t n wh ch the n t u ty of the phl m tis u t r upt d by th r mo l f a n r ow annul ba d f t ues xt r nal to the xyl m confirm the f t th t th yl m ti e pl y no s gn fi t r le i the c nd t n of gars Dur ng th d rm nt son when th fl w f water n the xylem c nd ts p tically cea ugar ften cc m lat th xylem sap in e d ly det ct bl am ts (e PLANT WATER ELA TIO S OF) h wev th a e ge m imal ncen tr ti ns a ld m e ed 0 05% f r mo t spec es altho gh a co centration as high a 8% has been re ported f th ug r m pl Ac sacch ru E en with th s speci ri ging th t m ir l p ox m ty t a term nal b d lts u h a evere r stri t on the pply of ga ic n t e t t th emerg nt shoot that g wth s greatly inh b ted (see PLANT GROWTH) It s ev dent th efo e that e n at th b gin g of the gr wth p od when th

omy involves the application of all other branches of plant science particularly genetics evolution morphology anatomy physiology and ecology

Modern plant taxonomy is the outgrowth of a long trial and error experience with methods of classification and arrangement The first scientific botanical writings were produced by the Greek *philosopher Aristotle* (384–322 B C) and his pupil Theophrastus (372–287 B C) Theophrastus who is called the Father of Botany listed the names of nearly 500 plant and some of these still stand as generic names in modern taxonomy These early Greek scholars arranged plants in three groups herbs shrubs and trees Little botanical knowledge was added during the next 1500 years

In the fifteenth century men again became curious about plants During the Middle Ages plants were classified according to their uses such as medicinal plants edible plants and poisonous plants About this time there appeared printed botanical *books called herbals which contained the descrip*tions of plants considered to have medical value In addition to the descriptions several herbals were illustrated with woodcuts Some illustrations were so accurate that today botanists can readily recognize the plants as they were originally pictured This period sometimes called the Age of the Herbals lasted for about two hundred years (1470–1670) During these years botany made the most steady rapid and consistent advance recorded up to that time This period however also produced odd and unscientific interpretations some of which still persist in certain quarters One of these the Doctrine of Signatures maintained that often the medicinal plant was stamped with some clear indication (signature) of its specific remedial power For example plants with yellow sap were said to cure jaundice

As the development of herbals continued botany advanced from a status of dependence on medicine to that of an independent science From the classification of plants according to their usefulness to man there gradually developed an interest in classifying them according to their own natural relationships Also there arose a growing interest in a more precise system of naming plants so that there might be much less confusion The publication of *Species plantarum (1753) by Carolus Linnaeus* a Swedish botanist marked the end of th old era in plant taxonomy and the beginning of a new epoch Linnaeus de eloped a method of classification ba ed primarily on the number of stamens in the flowers He consistently used the binomial nomenclature introduced by Caspar Bauhin (1560–1624) Linnaeus organized the work of his predecessors and fashioned it into a system by which the average per on could identify and name an unfamiliar plant He recognized natural relation hips but believed that only through an arbitrary arrangement could the vast number of known species be pre ented *in a* erviceable manner All these artificial systems of clas ification were predicated upon obvious superficial characteristics

However even before the close of the eventeenth century botanists had begun to improve plant taxonomy by making more clear and complet their descriptions of plants by defining categories more sharply and especially by attempting to di cover a natural basis of classification The efforts to produce an acceptable natural system were purred vigorously by the appearance of Charles Darwin s *Origin of Species* (1859) which focu ed attention upon evolution as a basis for natural relationships

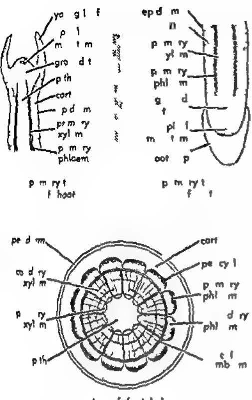
In 1866 Ernst H Haeckel coined the term phylogeny to designate the genealogical development in phyla of plants and animals Despite much attention phylogenetic taxonomy till remains in its early stages because of insufficient information concerning the evolutionary origin and development of the plant kingdom The true genealogy of plants is not known since this record is buried in the pa t ages Hence no scheme of natural classification reveals the complete relationship of all plants Tax*onomists try to place the primitive* plants at the bottom and the mo t advanced plants at the top of the scheme using morphological similarities and differences as the principal criteria As investigation brings more and better information cla sification methodology should improve resulting in greater refinement of existing procedures *See* PLANT CLASSIFICATION PLANT KINGDOM [P D S]

Bibliography Leroy Abrams et al *An Illustrated Flora of the Pacific States* 3 vol 1940–1951 L H Bailey *The Standard Cyclopedia of Horticulture* rev ed 3 vols 1953 N L Britton and A Brown *An Illustrated Flora* 3 vol 3d ed prepared by H A Gleason 1952 E L Core *Plant Taxonomy* 1955 M L Fernald *Gray s Manual of Botany* 8th ed 1950 G H M Lawrence *Taxonomy of Vascular Plants* 1951 P A Rydberg *Flora of the P airies and Plains of Central North America* 1932 P A Rydberg *Flora of the Rocky Mountains and Adjacent Plains* 2d ed 1922 J K Small *Manual of the Southeastern Flora* 1933

Plant tissue systems

Most plants are composed of coherent ma es of cells called tissues Large units of ti ues having some features in common are called ti sue sy tem In actual usage however the terms ti sue and ti*sue system are not strictly separated A* given ti sue or a combination of tissues may be continuou throughout the plant or large parts of it

Although classification of tissue systems may be ba ed on structure or function the two aspect u ually are combined Plant tissues are primary or ec ondary in origin The primary ari e from apical meristems the perennially embryonic ti ues at the tips of roots and shoots (see illustration) Th primary tissues include the surface layer or epi dermis the primary va cular ti sue xylem and phloem which conduct water and food respec tively and the ground ti sues The latter are paren chyma (chiefly concerned with manufacture and storage of food) and collenchyma *and scleren*chyma (the two supporting es) In the stem



t f d tyl d m
h w g p m ry d co d ry t

P ry d d ry pla t h e sy t m

a d oot, the v l r t ues nd me a o iated gr und t e are often t e ted a n t, the stel Gr d t s e m y be p nt in the e t r f th t le (p th) a d n t p r ph ry (pe ycle) Th gr nd t s y tem e cl s g th st l n the out s d th rtex It m y h e hypoderm pe ph lly a d an endod rm xt t th stel

The sec dary t es a e fr m l t ral m s tem a d the f mat n mainly esp n ible f the gr wth n th ckn s of stem and oots They mp i e ndary cul r tiss e and the p tect e t s called per d rm Sec d ry gr wth may bu ld up m r of w d b t th ter t y t m the b k r m n rel t ely thi beca ts ter lde rt become c r p essed d n m ny pe e s t n u ly l ghed off

The p od t f fl we n t d f v g t t e hoot r ult f m phys log cal and mo phol g al hanges n the apical m r t m wh h the b omes th fl w r meristem Th latt h w r od ces t u sy t m f d me t lly m l to those n the vegetat e body f th plant S ep t t n n les f r d t iled di u i n f th a s pl nt t ue y tems [K E]

B blog phy See PLANT ANATOMY

Plant translocation (organic solutes)

Th t pha e of pl t met bol m t l g the t ans port f g n c ompou d th gh th v s l t s- es (PHLOEM XYLE) f the pla t d s- tances of considerable magnitude relative to the siz of the plant for example from leaves to roots See LEAF (BOTANY) ROOT (BOTANY) In arborescent (treelike) speci s translocation d stances of ten exceed 100 ft

Large quantities of organic solutes are translo cated in plants For example in a singl apple tree under favorable condition about 150 kg of organic solutes tra slocated to the fruit during the ur e of the growi g season S FRUIT (BOTANY) In add n large qu nt ties are translocated from th leav t the growi g shoot tips and ro ts as well as significa t qua tities from the ro ts to the st ms and lea es *See* MERISTEM APICAL STEM (BOTANY) Ac or lingly ma y of the detail of the translocation process enta l problems of s gnificant c nc rn to pla t phy iol and agri ulturi t from both theoretical and p act cal viewp int

Importance of conductive tissues The relati e imp nce of phl em and xylem tissues as conduct ing lements in org nic transl cati n varies with the differe t ki ds of organic comp und and more sign fica tly w th th site of orig n r sy tl e is of the c mp nd in the pla ts Qua titatively the m t impo tant compou ds t an located i plants are s c e d erta n clo ely related oligos charides pri c pally raffino (*se* OLIGOSACCHARIDE) Such ompounds a e translocat d p dom na tly i th phl em both ba petally and ac op- etally that is in the d r ctio of the root and shoot tip re pecti ely Dur ng t ansl cati n in the stems co s derable fraction of the sugars n tran t m y m e rad ally from th phloem i t the o tex xylem r othe st m ti sue and accum lat s sta h oth conden ed p lyme par ticul ly n th ay c ll a d i p nchymato s ell imm d ately adj ent t the tr cheae the m wate cond t ng ves els (s PLANT TISSUE SYSTE S POLYMER)

Despite the p m ty f the e a b hyd ate re serves t the act wat ond ct ng ell in the xylem nly negl g ble q ant ti s f sug s pp a n th ap ext ct d f m the tracheal elem ts dur ng a major p tion f the grow g season Al o num o s r g ng xpe ime ts in wh ch the n tin ity of the phl m tissue s inte rupted by th emo al of n rr w an ular b nd of t ues ext nal t the xyl m co fi m th fact that the yl m t ue plays o s g fi a t ol n th cond t n of suga During the d mant s n when the flow f wat r the ylem cond it p t lly cea e sug s fte ccumul t in the xylem sap n read ly detect bl am nts (e PLANT WATER RELATIONS OF) howev the ag max mal c n n trat ons ld m c ed 0 05% f most sp c es alth ugh a co cent at on h gh s 8% has been re ported f th s g r m ple *A s ccha m E* n with thi pecies ng ng the stem n cl e pr im ty t t rm l bud res It n such se ere re- st ct n th supply of o g nic n trie ts t the eme gent sho t th t growth i atly nhibit d (PLANT GROWTH) It is ev dent the ef th t even t th beg nning f the growth per od wh n th

sugar content of the xylem ap ■ maximal for the season the importance of the xylem as a trans locatory system for sugar is negligible at least for the species that have been investigated in this re spect

Less data are presently available on the relative importance of xylem and phloem in the transport of nitrogenous compounds either in inorganic or organic combinations Chromatographic analyse of the xylem sap of many different species have been reported and reveal the occurrence of a large num ber of amino acids especially aspartic and glutamic acids and the corresponding amides also occasion ally urea and certain related ureide and alkaloids (*see* ALKALOID AMIDE ACID ASPARTIC ACID CHROMATOGRAPHY GLUTAMIC ACID UREA) The relative quantities of these compounds vary widely with species Inorganic forms of nitrogen espe cially nitrate N occur usually in trace quantities only or are absent altogether The concentration of the nitrogenous constituents in the xylem sap un like that of soluble carbohydrate remains mod erately high throughout the major portion of the growing season at an average concentration of about 0 03 *M* glutamine equivalent in apple for ex ample Conversely the concentration of nitrogenous con tituents in the exudate from ieve tubes of the phloem (this exudate is readily collected by mak ing an incision in the bark to the depth of the ac tive phloem as hown in Fig 1) i usually very low of the order of 0 001 *M* The e data provide presumpti e evidence that the xylem is the predom inant channel of transport for nitrogenous com pounds ■ pecially from the roots to the leaves fruits and stems On the other hand data obtained

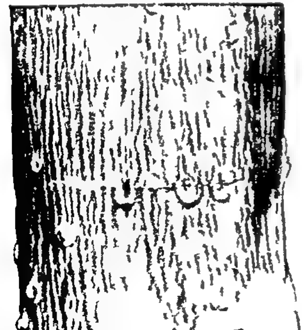
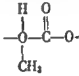


Fig 1 D opl t of e t b op d g f om a phlo m c o m d t the l 1 X X n the ba k of box-elder A ■ gu do (*Ph t graph by K L W bb a d R H H dg o*)

from a number of experiments in which con en tional ringing techniques were employed tron l suggest that the phloem ■ the major tran port tem For the pre ent these and other controversial data bearing on this problem can only be reconciled on the basis that the relative importance of the xylem and phloem in the tran location of nitroge nous compound varie with pecies the ontoge netic (life history) stage of the plant and variou environmental conditions Redi tribution of nitroge nous compounds from the leaves to other part of the plant i generally considered to occur mainl in the phloem

The increasing u ■ of sy temic pray compounds as insecticides fungicides bactericide and herbi cides on plants has centered con iderable interest in the study of molecular modification whi h in crease the absorbability and tran locatability of these compound (*see* ANTIBACTERIAL AGENTS FUNGISTAT AND FUNGICIDE HERBICIDE IN ECTI CIDE) Many carbamate for example ha e growth modifying and herbicidal effect but are not read ily translocated when applied to mature leave (*see* URETHANE) However by incorporating the lactic acid group



into the molecule as in lactic acid *N* phenylcar bamate or *α* carbodocecoxyethyl *N* phenylcarbam ate the translocatability of the molecules is greatl increased Closely related derivatives without the lactic acid group are not translocatable Much ork remains to be done on the general problem of mo lecular structure in relation to tran locatability Glucose and fructo ■ although frequently abundant throughout the plant are much le tran locatable than sucro ■ (*see* FRUCTOSE GLUCO E SUCRO E) Chromatographic analy es of the ieve tul e exudate from a con iderable number of different tree spe cies have revealed the consi tent ab ence of hexo e sugar except for the occurrence in a h (*Fra i us*) of mannitol the alcohol derivati e of manno e (*see* CARBOHYDRATE) Of true ugars only the nonreduc ing oligo accharides of the raffino e family ha e l een f und namely ucrose raffino ■ ta hyose and po ıl ly erl a c e The e ugar con tit ıte an a ending serie of di tri tetra and penta ac ha ride differing fr m each other only in the number of included gala to e re idues (ucro ■ none raffi no ■ one tachyo e two and verba co e thre) Su cro e i the dominant con tituent in tl ieve-tube exudate of all pecie tl u far analyzed except in a l in which ■ hy e occur ■ the highest on entrat n The total tachyo e c ncentrati n ranges fr m 10 to 25% varying with peci and in li id ual tree and fl ıctu ting di rnally and sea onall In S cily thi s igar i harve te l from vari u spe ■ of a h tree e p cially *Fra inus* ■ *nus* by

Fig 2 St l ct t t g ery t ll d f m tube sap e d g f m m d th b k f osh r s (F m B H b B d t b t G 66 9) 340–346 1953)

tapp ng th m ve tub a show in Fig 2 The crystall zed x d t f rm m ll t la t te g s t k wh h may b h rvested at c e enc

Wheth th ev t be p c n be c n d ed w th c rtai ty t t tut v lid s mpl of th g c lut t t n t kn wn b t ml e n l s g d n th l t t lo tabil ty of u r d h ha e b e ached f m d ta b sed ad hem al ys (e RADIOCHEM IS-TRY)

Requirements for organic nutrients Th pe-fic req m t f f t f g n nut ent o tr t precu t nsl at d t t from the p rt of the pl nt em t b l ti ly f w d pl Exc d p lt at d la e ov ie of the t m t d gh k n c n grow m tr d f rm l t wh h m ally e en p du nd a c lt med m e t ng o ly su e th l mpl me t f g n (t t ph ph s ll t cal m m g e m and forth) nd w te S FLOWER (BOTANY) PLA T MI ERAL NUTRITION S E D (BOT Y) Alth gh g n f t d ff ce th h mi l c mp t n (fru t of a g ty may be exp t d wh n k fied nt r u tock a t th tu l d f f nce t m ca es pp t b q t g l gibl (GRAFT G OF PLANTS) F r mple

grafting y ung ur l mon fr its w thout the s on lea e n t a weet lemon tree or vice ver a does n t mat riall change the organ c a id ompo iti n of the r i ti e f uit when m ture (F g 3)

Th s is n t to imply h we er th t th root tock ha no eff ct o th ch mi l c mp ti n and q ial ity of the fru t. Co n t tent differe ces ha e b en fo nd f r ex mple in the bitt rness of th ju ce of the Wa h n t n Navel orange r lat ble to the type of oot t ck u d Stock cion relatio h p are al o impo ta t i many indi ct ways ch as dis a e re ta ce and c ld h rd e s *See* PLANT DI EASE CONTROL

In v ew of the fact that the prep nderanc of or ga ic lutes re tran located thr ugh the phl em ell c n ider bl re earch has been directed to-wa d a l a e el cid ti n f the physi logy of thes cell n der th t bette unde ta d ng m y be g ned of th m chan m of transl cat o a d f the f ct r both n ronm ntal and internal whi h i fl nce thi proce The techn l gic l impor t n e of these tudie d ri es from the fa t that many rop m nagement practic a i th ir final analy ffort n the pa t of the ag i ultur t to control the r t and d r ti n of tr n locat on of o g ni mpo nds f om d no to a cept r areas with n the plant a from lea e t r ot or le to f t S AGRICULTURAL SCIE CE (PLANT)

Fg 3 L m F t g ft d *May 4* d phot q ph d M y 29 Fru t w 51 4 mm d m t wh g aft d d 65 2 mm wh m t o D mbe 11 gr g) l r d re n l m f 63% (F m L C E k S 125 3255) 994 1957)

sugar content of the xylem sap is maximal for the sea on the importance of the xylem as a translocatory system for sugar is negligible at least for the species that have been investigated in this respect

Less data are presently available on the relative importance of xylem and phloem in the transport of nitrogenous compound either in inorganic or organic combinations Chromatographic analyses of the xylem sap of many different species have been reported and reveal the occurrence of a large number of amino acids especially aspartic and glutamic acids and the corresponding amide also occasionally urea and certain related ureides and alkaloids (*see* ALKALOID AMIDE ACID ASPARTIC ACID CHROMATOGRAPHY GLUTAMIC ACID UREA) The relative quantities of these compounds vary widely with species Inorganic forms of nitrogen especially nitrate N occur usually in trace quantities only or are absent altogether The concentration of the nitrogenous constituent in the xylem sap unlike that of soluble carbohydrates remains moderately high throughout the major portion of the growing season at an average concentration of about 0 03 *M* glutamine equivalent in apple for example Conversely the concentration of nitrogenous constituents in the exudate from sieve tubes of the phloem (this exudate is readily collected by making an incision in the bark to the depth of the active phloem as shown in Fig 1) is usually very low of the order of 0 001 *M* The e data provide presumptive evidence that the xylem is the predominant channel of transport for nitrogenous compounds especially from the roots to the leaves fruit and stems On the other hand data obtained

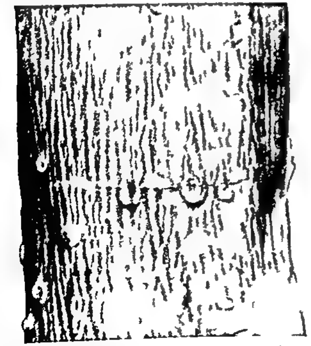
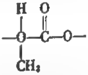


Fig 1 Droplets of sieve tube sap exuding from a phloem incision made at the level XX in the bark of box-elder Acer negundo (Photograph by K L Webb and R H Hodgson)

from a number of experiments in which conventional ringing techniques were employed strongly suggest that the phloem is the major transport system For the present these and other controversial data bearing on this problem can only be reconciled on the basis that the relative importance of the xylem and phloem in the translocation of nitrogenous compounds varies with species the ontogenetic (life history) stage of the plant, and various environmental conditions Redistribution of nitrogenous compounds from the leaves to other parts of the plant is generally considered to occur mainly in the phloem

The increasing use of systemic spray compounds as insecticides fungicides bactericides and herbicides on plants has centered considerable interest in the study of molecular modifications which increase the absorbability and translocatability of these compounds (*see* ANTIBACTERIAL AGENTS FUNGISTAT AND FUNGICIDE HERBICIDE INSECTICIDE) Many carbamates for example have growth-modifying and herbicidal effects but are not readily translocated when applied to mature leaves (*see* URETHANE) However by incorporating the lactic acid group



into the molecule as in lactic acid N phenylcarbamate or α carbodecoxyethyl N phenylcarbamate the translocatability of the molecules is greatly increased Closely related derivatives without the lactic acid group are not translocatable Much work remains to be done on the general problem of molecular structure in relation to translocatability Glucose and fructose although frequently abundant throughout the plant are much less translocatable than sucrose (*see* FRUCTOSE GLUCOSE SUCROSE) Chromatographic analyses of the sieve tube exudate from a considerable number of different tree species have revealed the consistent absence of hexose sugars except for the occurrence in ash (*Fraxinus*) of mannitol the alcohol derivative of mannose (*see* CARBOHYDRATE) Of true sugars only the nonreducing oligosaccharides of the raffinose family have been found namely sucrose raffinose stachyose and possibly verbascose These sugars constitute an ascending series of di tri tetra and penta saccharides differing from each other only in the number of included galactose residues (sucrose none raffinose one stachyose two and verbascose three) Sucrose is the dominant constituent in the sieve tube exudate of all species thus far analyzed except in ash in which stachyose occurs in the highest concentration The total stachyose concentration range from 10 to 25% varying with species and individual tree and fluctuating diurnally and seasonally In Sicily this sugar is harvested from various species of ash trees especially *Fraxinus ornus* by

Fig 1 T b o m ympt m o t bo l f h m sa ll t e lt f m th d t b t f th ght d d k g Th wht d e t oc l l p t f th t u in th p t y t t of th (Ph t g ph f m L O k)

hl phyll in w g owth e t e b n h g g e ng of fl we p tals nd the ymptom (F g 2) St ll th u es c g lls t mors d d t ak d te nal killi g f sp c fic t s (F g 3) I d d I pl t cell m y b d d in z k ll d t mul ted t enl g r d d Cell rg ll m y h w ympt m d incl on of i k d m oc r n th yt pl m r nu) (CELL NUCLEUS CYTOPL SM) Some of thes t tyst I of ru (F g 4) All ti ue m y b aff cted o the u m y ha e pr f e t l affi ity f p r chym phl m o ylem (e PA E CHYMA PHL EM XYL M)

Pl t ru ympt ms are m k dly i fl e ced by n me tal d t ons s h a t mper t re l ght, nd mine al nutr t o Wh n inf t ns are t m r t i the o d ary n nme t th plant in ol ed is refe red to as a symptomless carrier a d cultivated plants weed or ther wild plants f this sort m y b among the importa t r ervoir sources of viru for a particular di ease

Transmission of viruses Fortunately few vi ru es are tr nsmitted thro gh eeds or pollen of plants H wever becau e of the u ual systemic na t re of the infection most viruses are perpetuated in plants which are p opagated egetati ely by su h means as cutting bulb r ot and grafted roots (se GRAFTING OF PLANTS REPRODUCTION PLANT) A gre t many cult ated plant for xam ple potatoes and sugar cane are propagated e etati ly and it is n these th t ir ses cau e th greatest losses

Almost all pla t iru es can be transmitted by gr fti g a portion of a d sea ed plant onto a sus ceptibl h lthy pl t Th s one of the m st en ti m th d of a certaining whether a may b in ol ed in a d ea e A few ir e are tran mitted by any t rele i g a minute amou t of sap from a di ea ed cell and introducing it nto a he lthy cell f r ex mpl w d rubb ng l e togetl er finger u tool to ching pl t S me are t a mitted by mites and ome by l n m t des (ee ACARINA NEMATODA) H we r m t pla t ru es re tran m tted by insect a few by b t ng in ects s ch a b etle b t mo t by k ng ects such ph d d leafhoppe s Alm t all of them e t a m tt d by onl k nd f n ct (s ENTO IOLOGY ECONOMIC INSECTA)

There are se e l k ds of relat hips between th iruse a d the r i ect c r In ne r lat on I p the t acquir v us o i the tip of its m ute s k g tubes d ng a pr be of a d a d pla t a d t ansmits it wh le maki g im l r p bes of healthy pl ts I othe type the vi us s t ken int th body f the in e t ca r er a d nly aft it mult plie the for 1– weeks does th i t b g t tra m t it. F r the est of it l fe

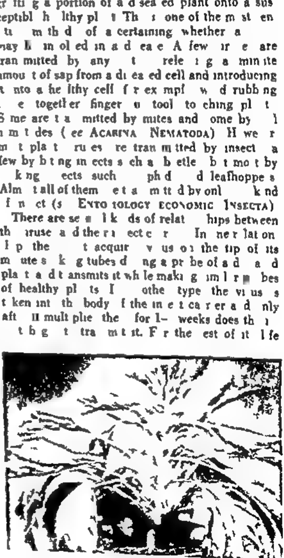


Fig 2 P olf t g h t w th ltt! hl phyll g th l f b s f o t pl nt f ct d by t y fl w Th fl w p t ot th t p t f m d t l flk t ctu lm t d ld f p gm t Th ld l y ll w d th m m fl th l f wh th d Frst d l p th l th ff ct

Mechanism of translocation Any mechanism which is proposed to explain the translocation of solutes in the phloem must take into account the following facts

1 Living cells are essential Unlike the transport of water and inorganic solutes in the xylem transport of organic solutes in the phloem can occur only through living cells Killing the cells in a localized zone of the stem for example with steam boiling water or hot wax is as effective a barrier to the transport of phloem limited solutes as is complete removal of the phloem by ringing However the specific cells in the phloem through which the major fraction of the solutes is considered to be translocated namely the sieve tubes and other sieve elements are enucleated cells and on the basis of various cytohistochemical observations it is commonly held that the protoplasm of these cells is relatively inactive metabolically compared to that of the other tissues (*see* CYTOLOGY PROTOPLASM) Nevertheless it is apparent that a certain minimum level of metabolic activity is essential (*see* PLANT METABOLISM)

2 Rate of translocation is rapid The rate of dry weight increase in fruits tubers and fleshy roots reflects the rate of organic translocation and this quantity varies for different species and environmental conditions from about 0 03 g/hour to in excess of 2 g/hour when averaged over the entire growing season (flowering to harvest) The velocity required to account for these known rates of translocation is about 1–2 cm/min based on the assumption that the entire cross sectional area of the sieve tubes (exclusive of the walls) is available for transport Direct measurements of the velocity of translocation of radioactively labeled compounds through stems provide comparable values It has been estimated that the rate of translocation is 10 000–100 000 times faster than can be accounted for by diffusion

3 Translocation is frequently polarized Growing regions on the plant especially rapidly developing fruits exert a strong monopolizing effect on the distribution pattern of organic solutes translocated *from the leaves and other areas of synthesis or storage* This polarizing action of fruit is established during the early stages of embryo development and does not develop in the absence of pollination in nonparthenocarpic fruits In apple trees it has been shown that for a constant ratio of 30 leaves per fruit the leaves and fruit can be separated by distances up to 10 ft (the maximal distance varying with plant variety) without any loss in the size *and quality* of the fruit

None of the current theories which have been proposed to explain the mechanism of solute translocation in the phloem is capable of reconciling all of the known facts regarding this process The theory that has received the most general acceptance despite a number of admitted limitations is that developed principally by E. Munch about 1930 and known as the *Druckstrom* or pressure-flow mechanism According to this theory modified to take into account newer information and concepts there is a flow of solution within the sieve tubes in the direction of a positive turgor pressure or hydrostatic pressure gradient that is from a region of higher to a region of lower turgor pressure within the sieve tube This pressure gradient is established and maintained osmotically as a result of the metabolic entry and removal of translocatory solutes principally sucrose into and from the sieve tubes. The entry of sucrose into the sieve tube at donor sites and its removal at acceptor sites appears to be in many cases against a concentration gradient, and hence must be a metabolically actuated process. It is known that the process of translocation is sensitively influenced by the physiological status of the donor and acceptor organs

Other theories on phloem translocation, for example the cytoplasmic streaming hypothesis, attribute a more active role to the individual cells or elements of the sieve tube In brief however the present status of the overall problem mainly favors the view that the sieve tube protoplasm does not possess per se any metabolic machinery capable of driving the translocation process, except for metabolically activated transfer systems which move solutes across limiting membranes at the sites of entry and exit into and from the sieve tubes. Throughout the major portion of the transport distance it appears that the solutes are simply swept along at different rates by solvent drag forces resulting from the osmotically actuated flow of water through the sieve tubes [C.A.W.]

Bibliography O F Curtis *The Translocation of Solutes in Plants* 1935 B S Meyer and D B Anderson *Plant Physiology* 2d ed 1952 E Munch *Die Stoffbewegungen in der Pflanze* 1930 F C. Steward (ed) *Plant Physiology A Treatise* vol 2 1959

Plant virus

Viruses attack many higher flowering plants, but with the exception of the viruses which attack bacteria or actinomycetes none has been definitely shown to infect lower forms in the plant kingdom *such as ferns mosses or algae* Some viruses attack many species of plants in many genera and families others appear to be limited to a single family

Virus symptoms Symptoms may occur in any part of the plant including the roots The most common symptom is mosaic that is patterns of light and dark green areas in leaves (Fig 1) In most virus diseases mosaic or other symptoms are preceded by clearing of veins in the leaves of new growth Some of the older leaves may show primary lesions for example yellow spots at points where the virus was introduced Sometimes there is a mosaic pattern on the stems or fruits as well as on the leaves or the flower petals may be variegated The earliest records of plant viruses are Dutch paintings of symptoms in tulip flowers

Types of virus diseases There are various types of virus diseases One cau lack of

Fig 5 Fo f m f pl t v ru oll m g fi d p- pro t ly 40 000× ( ) Tob m c straight rod Th f ct s part l p b bly l W t d rd l gth (ph t g ph f m J B d) (b) Beet y ll w fi bl fl m t t l t d t t y llows (ph t g ph f m J B d) (c) Wo d t m Ex m t gg t th t th p rt l p lyh d l Th l g p rt l f t ph (ph t g ph F m M K B kk A E V H d L M Bl k) (d) U d the l ct m p potato y ll w-dw rf u os m u h p p f g ball sa g s d d fl t d b ll (lect ph t g ph f m M K B kk o d A E V t)

l ed rt n p t t v r t th t ar n fected by o m r e p oduc g o o- u b) ympt m Co t ol me m l de q r t br ed g f d e t t n e kill ng eed a d t p t n rvi es t fied ed nd m ny th p t e that h ve bee f tal mp rt n e ma nta ng p y eld nd q l ty S PLANT D SEASE PLANT DISEAS O TR L. [L M B]

Bibl g ph y K M Sm th *A Textbook f Plu t D* 2d ed 1957 K M Smith a d M A L g (d) *Ad n l us R ch* ol 1-6 19 3-19 9

Plantaginales

A m ll d r f the pla t bel D tyl d a h ng a gle f m ly w th 3 gen a d 00 p es f m p l t n a g Th pl nt e h rb eou Th l es e ette th fl r e se pose p t te p at a d th f u t a c m l p ul rr g th t t p n l g t g la t a g dl g l M t of th ew ed b t the fl w t (*Pl t p yll m*) ult ted Spa a d F a c f p yllum d sed s l t S DICOTYL DONE E E s PHYT PLANT KINGDO [F D S]

Plasma physics

That fi ld f ph wh h lat t the t d f h ghly ed g es h g wh ch mp d f a l qu l ml f p t nd gat f ha ges (pos t n a d l t n) ll d pl m fi r l g ld f t b l l a g

B cau e it i compo ed f charg d particles a pla m exh b ts ma y phe omena not enc unter d in ord nary ga In ad lit o t their importance i ma y n w ar a f ppl ed c ence the e eff cts are evident i trophy cal ph n mena (mo t f the matter i t m e e exi ts in the pla ma st te) both in t llar atm phere and in nter t llar p PI ma phen mena l a e al been ob rved n the ion u t nized ga f the e rth s oute atm phe e S COSMIC ELECTRODYNAMICS

P actic l t e t in pla m phy i a i e fr m v r ous appl catio s of g di h rge fr m the tudy f ele tr n be m in el ct on tube and from the ew earch fields f ult a high temperatu e p ce es a d o tr lled f io (s e FU ION NU CLEAR PINCH EFFECT) In the e latt r experi ment m ll n r e h nd d f mill n of de gre ki tic tempe at re are eq red (ki eti t mp at re i defi ed lat r) To ol ta n a ompr hen ve phy ical p ct re of pla ma it i nece ary t c id r t b hav o from tw d ffe ent a pect

1 Th m r c p e pict re rel ti g t its pa t lel ke prop rt ch a th eff ct of nt r pa ticle oll i n in pr du ng diffi o and ther t ansp rt ph mena ion zat n x rad at n nd ther pa ti ulat p es In th p tu e a pla ma h bit pr pert me f which a m h like tho of any g s

2 Th mac p p tu wh r th lle t e or fl dl k p perti e m t id nt The e p pert e lud cond ict f le tr ity p p gat n f ou k nd of w and ab l ty to upp t la es f n t kle a d turb le t b h v r pe l a t cond t ng fl d M ny of the m cro- c p p ha l p pe t s f pl m a e elat d to th ge al fi ld of m gn t hyd dynam (se MAGNETOHYD ODYNAMICS)

The h rg d pa t les f a pl ma t t with ea h the th gh the l tro t t c or C l mb field w th which ea h t rr u d d O the micro- scop ale th l t o tatic f ld g ri to lo al z d attr ti e r p l i e fo e b twe n the part cl th y pa r to each othe r s lt g m t l d fle t on On the m ro p c le th umm t on f th many infin t mal le t t t a d magn t c field p du d b th m v ng pl m part le e ult n a m d t o g d l trom gnet fi ld Th pl m th n rea ts ll t ely that s ndu t n fi d t th t tal el t omagneti fi ld wh h t s mme ed Th fi ld st f th mb n t on f th pl m elect mag et fi ld a d ny ex t r lly imp d fi lds The o pl d of the pl m m t n d th l t omag et fi ld n wh h t m e th u e f m t f th m ple ty f pla ma beh ior

CRITERION FOR PLASMA PHENOMENA

A l gth cal wh h pp mately di de the m o op d m f m th m ro c p d m n n pla m t th o- ll d D by r en ng d t e λ It a l h w th t s l ng as th d

Fg 3 Tumor c tt d o e the oots a d ma sed at the c w of a o l plant fe ted by wo d tumo v r s

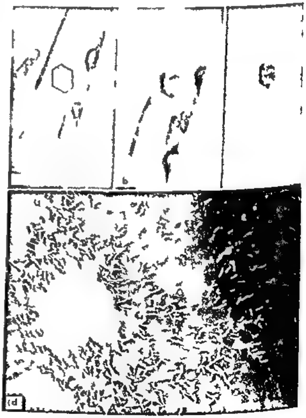
the in ect may conti ue to transmit the virus Some of the e insects are known to be diseased by the virus and pas it to their young through the egg Howe er none of the plant viruses is known to at tack higher animals

Structure and chemical composition Viruses have various shapes—rods flexuous filaments spheres polyhedra or plastic forms—all of wh ch are too small to be seen with the light micro cope but have been resol ed by the electron microscope (Fig 5) The principal components of viru es are protein and nucleic acid the latter carrying the hereditary determinants The single trand of nu cleic acid occurring in each tobacco mo aic virus particle if eparated from the protein without be ing broken is infectious whereas the protein i not The nucleic acid strands and subunit f the protein can be recombined in the test tube to re constitute virus particles The nucleic acid can al o be chemically changed in the test tube to produce mutants of the virus The e discoveries have con tributed to our basic understanding of heredity (see MUTATION NUCLEIC ACID VIRUS)

Mutations of most plant viru es occur pontane ously and are readily isolated in the laboratory In nature such mutations also occur but here strains showing greater differences from ea h other are also found which for their development probably require evolutionary intervals not availa ble in the laboratory

When a virus is introduced into a plant, the pro tein apparently separates from the nucleic acid Freshly formed free nucleic acid and protein ub units appear in the cells before the completed viru particles The infective agent is assumed to pread through the microscopic protoplasmic trand (plasmodesmata) connecting one cell with an other through the cellulose wall (see CELL STRUC TURES) Passage through the parenchyma cell i slow but transport through the vascular elements (food and water conducting cells) is rapid

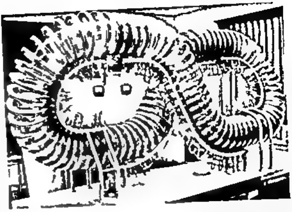
Economic importance Lo es from plant viruses vary from the destruction between 1936 and 1946 of 7 000 000 orange trees by tristeza di ea e in the state of Sao Paulo Brazil to the insidious ann al



Fg 4 (a) Crystall e l bod e of t b c mo s c u ph tog aphed a l g ell of tobacco pl t mag fed 500× (b) The am c ll a d cryst l l l s o ofte f e-d y ng mag fed 500× ( ) Th f o -d d ry t l remo ed f m th cell m g f d 500× (d) A p tally d ol d f gm t of the am l cl s on d lo g th t t co st of tob cc mo a s part cl m g fed 11 000× (*Photo g ph f m R L St a d am*)

e periment ti n is 50 000–100 000 K, a d r nge ptoten o h ndreds f m ll on of d g ees

R turning t the q e ti n of produ i g the pl ma by m zati f a g ne ecalls that s h p oc e c r i o di ary ga o s di h rg s f e ample i flu re ce t lamp Howe r in such d h g the d elect o of the pla m a c ti ally a d p dly be ng c ol d nd c m b d by c t t w th th chambe w ll that th t mp r t re s l w a d the t t f n zat n s ly p rt al d can be mainta ed only by a la ge t i p t f e rgy A n ry alternati i t find om m f elect m n tic c fi e m t f th pl ma n e c ated that ts par ti les c t t h the chambe wall Effe ti co fi eme t is th p me bje ti of high tem



Fg 2 St ll t Th fg e-8 h p p t t t d ft f th pl m

p r t re pla ma re e rch and m th basis f r hopes of ch ing ontroll d n cle power fr m nuclear f i n re ct o i hot plasma With t ch me s high temper ture pla ma e n f t ould b e ted w uld h ve ly a fle ting exi t nce typically les th n a m ll o th of a eco d

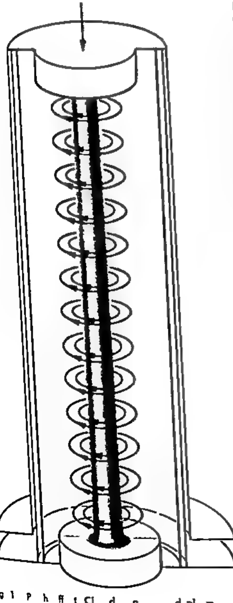
Magnetic confinement The pi ch effe t epre nts the mple t ex mpl of magnet c confinement ll st g ele tr c urre t i p ssed thro gh the body of th pla ma elf magnet field con fig rat on of cl ed ri gs (hown in F g 1) is c e ted P allel urre t elements attract that is th body f ce $\mathbf{J} \times \mathbf{B}$ ($\mathbf{J}$ = c rent de s ty $\mathbf{B}$ = m gn tic fi ld st gth) i alw ys wardly d e ted th co t ting the pl m Fr m anothe po t of w the magneti li e of f r be ha g a el ti b d su nd the pla ma col umn d p d a h p stre wh ch re i ts th outw dly d r t d kinet pre s e f the pla ma Th nt I eq red t balance th plasma p s su e en by th Be ett relat hip

$$I = 2\,NkT \qquad (2)$$

whe I in amp e N s th t t l n mbe of p t le pe l l cent m t f th p h k B ltzm n ta t d T th k et tempe t e f th pl m

C fi ment f pl ma by t lly ge erated m g t fi lds l n bl Tw ge ic c r d t g h bl

1 Th St llar tor (n e ted by L. Sp tze Jr) mpl fie co fl ment i an e dl t be of m d fi d t d l f m (Fi 2) I th St ll at t g m gn t fi ld p ll l to th t be wall g at d by e te al l p n ts the pl m f m t h g the chamb w ll S l g t d l mag t fi ld h l ttl i fl e n pl m m t al g the l f f e t ece ry t l th t h t elf T d ce ta t d ft f th pl m wh h w ld b p t if th St llar t w t t d a mple t th fi ld l g a h l l tw t th by mea f p l a x l ry l th t St ll by m k g th t b th f rm f fig e 8



Fg 1 P h ff t Cl d g d pl m p- ent mag l f f

Values of λ_D for typical densities and temperatures

n electrons/cm	λ_D cm: T (K) 10 (8 6 ev)	10 (86 ev)	10 (860 ev)	10 (8 6 kev)	d cm $(1/n_e)$
10	0 22	0 69	2 2	6 9	1×10
10	0 02	0 069	0 2	0 69	$4\,8 \times 10^{-}$
10	$2\,2 \times 10$	$6\,9 \times 10$	0 022	0 069	$1\,0 \times 10$
10	$2\,2 \times 10^{-}$	$6\,9 \times 10^{-}$	2×10	$6\,9 \times 10$	$1 \times 10^{-}$
10	$2\,2 \times 10$	$6\,9 \times 10^{-}$	$2 \times 10^{-}$	$6\,9 \times 10$	$4\,8 \times 10^{-}$
10	$2 \times 10^{-}$	$6\,9 \times 10^{-}$	2×10	$6\,9 \times 10^{-}$	$1\,0 \times 10^{-}$

less than λ_D normal Coulomb attraction or repulsion will exist and one can define the encounter as a simple collision to which the ordinary laws of particle dynamics apply (see COLLISION) However if the minimum distance of approach of two particles is greater than λ_D the collective motions of the surrounding plasma electrons induced by the passage of the particle will be such as to screen the test particle from feeling the influence of the other particle (or any others beyond the distance λ_D)

The length λ_D depends on the density n and the kinetic temperature T of the plasma electrons It is usually defined through the relationship

$$\lambda_D = \sqrt{kT / 4\pi n e} \quad \text{cm} \qquad \text{(cgs units)} \qquad (1)$$

where e is the charge on the electron and k is Boltzmann s constant

Values of λ_D for typical plasma densities and electron kinetic temperatures of interest in laboratory experiments are listed in the table Kinetic temperature refers to a measure of temperature in terms of the kinetic energy of random motion of the particles of gas In a maxwellian gas the mean kinetic energy $\overline{W} = \frac{3}{2} kT$ where T is the absolute temperature in degrees Kelvin (see KINETIC THEORY OF MATTER) A convenient measure of $\overline{W}$ is the electron volt so that kinetic temperature is often measured in electron volts 1 ev kinetic temperature = kT = 11 600 K = $\frac{2}{3}\overline{W}$

In the last column of the table the approximate mean particle separation $d = (1/n)$ is given for comparison Except at the highest densities λ_D is seen to be substantially larger than d corresponding to the fact that many particles are contained within a Debye sphere so that each particle lies within collision range of many other particles at any given time This is of importance to the understanding of certain collision effects in a plasma

The numerical value of λ_D provides an important criterion by which to decide whether in a plasma of given size collective phenomena are to be expected Certainly if the over all dimensions of a region containing plasma are small compared to λ_D only simple collisional or single particle behavior is to be expected the plasma will behave as an ordinary low density gas and collective processes will not be important Conversely if the dimensions of a plasma region are very much larger than λ_D the possibility exists for collective plasma phenomena Thus as seen from the table in the laboratory where dimensions are measured in centimeters plasmas with electron densities less than about 10^{6}–10 cm would not be expected to exhibit collective behavior These are particle densities which are typically encountered in conventional particle accelerators On the other hand, in the earth s upper atmosphere λ_D would be much smaller than other typical dimensions for all electron densities higher than a few electrons per cm In such cases collective effects could be expected to be possible even at the lowest particle densities encountered

The condition just given admits of another simple and useful physical interpretation Consider a sphere of plasma with radius λ_D and assume that nearly all of the electrons of the plasma are removed to infinity from this region The removal of these electrons will leave an uncanceled positive charge and a resulting radial electric field From the definition of λ_D it is then easily shown that in this case the energy necessary to remove the additional electrons from the plasma is (within a factor of two) equal to their mean kinetic energy It follows that if $\lambda_D \ll$ the plasma dimensions any influence which tends to separate the bulk of the plasma charges by a distance greater than λ_D will give rise to strong electrostatic restoring forces which will prevent any further separation Conversely if $\lambda_D \gg$ the plasma dimensions the electrostatic forces arising from even a complete separation of charge will have little influence on the motions of the individual charges so that collective effects will be unimportant

CREATION OF A PLASMA

To create a plasma in the laboratory it is usually necessary to start with an ordinary gas at a small fraction of atmospheric pressure and then to heat it by electrical or other means until the mean kinetic energy of the gas particles becomes comparable to the ionization potential of the gas (see IONIZATION POTENTIAL) Mutual collisions of the gas particles will then result in a cascading ionization of the gas Since ionization potentials are always several volts such effects are only important at kinetic temperatures of several electron volts so that the threshold tem … most plasmas

PARTICLE DYNAMICS IN PLASMAS

Magnet c o fi eme t d ff s n of a pla ma a r a magnet c field and other ch ra teristic of pl ma n be bette d t od by eturn ng to the m r c p c p ture Ea h harged part cle f the pla m m s in the m othed out elect omagnetic fi ld f m th c mb n ti n of th external ppl ed field d the el ct and magn t c fields p f d by th pl ma it elf In m ny c c ll s ns at inf eq nt nd th fi ld a well e ough k wn t ll w pred t f the part cl mot h relat ely mpl te h que

Th qu t o f m t n f charged particl f m M v locity v nd ha g e i an a bit ary l t d m gnet fi ld i

$$F = M\frac{d}{d} = \left(E + \frac{}{c} \times B\right) \quad (\text{cos} \quad \text{ts}) \quad (7)$$

h th el ty f l ght

I m ny c e f p ct cal s te t $E \ll B$ a d B will be rel t ly sl wly rying in time a d p In s ch c e the solutio to Eq (7) ep t b t h h e appr x mate hel ce (o l p ing h p d) o e po d g t a tat n f the p t le a d a l ne f f r s p rp d n a l lt al m t l ng the l f f e (pa all l a t p rallel to the d ect n f B) I th mpo t of mot pe p nd cula to th di ec t f B Eq (7) ed c s mply t a tr fugal f ce qu t n

$$F = \frac{M}{} = \frac{eB}{} \quad (\text{gs un ts}) \quad (8)$$

th t a r t tio t th y lot ng la f q cy

$$\omega = \frac{e}{} = \frac{B}{M} \quad (9)$$

Th f qu n y s cle ly mu h h gh r f el ctr n th f p t e i n

Correspond ng to the e f eq e f rotat th r d f urvat re f th o b t als g v n by l g Eq (8) f s

$$= \frac{M}{B}\frac{2W}{M} = \frac{1}{}\frac{2W}{M}$$

wh r

$$W = \quad M \quad (10)$$

F th me W m h m ll r f l t n of m m tha f n r e p nd g to lu t

$$= 3.4W \; / \; /B \quad m$$
$$(W \ll mc^2 = 511\ \text{ke} \quad W \quad)$$

F n

$$= 1.4\ (A \quad /Z)(W^{1/2}/B) \quad m$$

Wher f th m f th n at m c m it T t k a e ampl f $A = Z = 1$ (p t) F 10 e d $B = 10$ s th $= 145$ cm At the me energy and f eld trength r is only 0 34 mm I this ca $\omega = 9.5 \times 10$ rad/ ec and $\omega = 1.75 \times 10$ rad/

Retur i g to th quati n of m ti Eq (7) o may n w p e sely define the d ti ns under whi h mpl s luti ns are obtained It is only re quired that B ho ld ary lowly i time com pa ed w th (ω_{ci}) d by a mall amount per c nt g wise ov r n orbit radiu that is

$$= \left(\frac{1}{B}\frac{\partial B}{\partial t}\right)^{-} \gg 1/\omega \quad \text{sec} \quad (11)$$

$$\lambda = \left(\frac{1}{B}\frac{\partial B}{\partial}\right)^{-1} > \quad \text{cm} \quad (1\ )$$

The e ar the o-called cond t ns of ad ab tic ty f the particle m tio

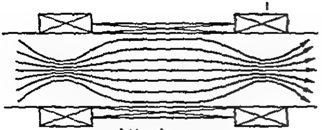
If the c ndit on a e ati fied me ery m po tant n q en e f ll w The e a e ( ) that the mot o of any ch rg d p rti le an be well repre ented by f llow g the mot n f it in ta tane u ce te of r tat on r g id ng nt r (i) th t the gu ding ent rs will mo ab ut w th re p ct t th magn tic l e with l w dr ft loci es pred table f m mpl law and (i) that m ny f the al ent featu es f th m ti n can be pre c bed n t rm f ne rly n tant quant ties kn wn ad abatic n a ts

Drift velocities A mpt n (11) d (12) an be u ed to lc l t d ft el cit Th s mple t a d m t importa t of the e el t e f ll w by n pe t n of Eq (7) If th pl m p t cl m e i a l tri fi ld w th a c mp nt t n e t B then the g id ng nt f ea h particl w ll dr ft n d ect o perp dic la both t E d to B with l c ty wh h s depende t of th ch ge ma o ne gy of th pa t cl Th a lo ty g en by

$$= c\frac{E \times B}{B^2} \quad \text{cm/se} \quad (13)$$

The der ti n f Eq (13) f m Eq (7) f l l w mmed at ly if t s ted th t n a f ame of fe e m ing at l ity v the mot onal elec t c fi ld j t c c l th applied electri field a d th p rticle m t are ag in helic It n l ded that an le tric field mp t p p nd c l r t B a s th pl m t mo e a d d stort lo lly a alw ys t m ke the elect i field n t h th pl m s wn f am of efe en e Thi s j t th b h r whi h w ld b xp ted f c mp ibl highly nducting ga Furth r anal y h w th t th p p ty i l d ntifable with t ng t den f the pla m t p eserve n ta t magn t ll x throu h h of t l m l ment t mo f m pl ce to pl c or ub- je t d to l wly v y g magn t c fi ld

The dr ft el ty v i l relat d t th par d x c l t ti wh eby j t f pl m n o s thr gh v t d g n e nt ng a t o g tra m gn t c fi ld If a pla ma jet i im p ll d at v loc ty to h a r g n a ry



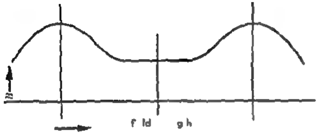


Fig 3 Mag t c m ror The h l x n th pper part rep esents the path f a part cle in the plasma The cu e below epr e ts the magnet c field strength B along the path u n the tub

2 The mirror machine (invented by R F Post) allow confinement in a tube with ends "plugged" by magnetic mirrors (Fig 3) A magnetic mirror is merely a localized region where the magnetic field i made much stronger than average so that charged particle tend to be reflected a they approach the mirror The magnetic mirror effe t is well known from co mic ray physic where it is encountered in the reflection of co mic ray particles by the earth s magnetic field It has more recently been identifi d a the explanation of the trapped particle or Van Allen radiation belts of the upper atmo phere where the earth s dipole magnetic field creates a natural m ror machine See COSMIC RAYS VAN ALLEN RADIATION

Pressure balance and diamagnetism The magnetic confinement of a plasma can be identified with a diamagnetic effect a ociated with the pla ma that i the introduction of a pla ma into a region containing a magnetic field tends to weaken the magnetic feld in that region (see DIAMAGNETISM) This effect is readily seen in the pre sure balance relation hip for a confined pla ma If a (usually) small effe t ari ing from the curvature of magnetic lines is neglected this relation hip is

$$\nabla\left(p_\perp + \frac{B^2}{8\pi}\right) = 0 \qquad (3)$$

where $p_\perp$ i the local value of the compo ent of the plasma pre ure perpendicular to the line of force and B is the local field trength This expres sion which shows the constancy of the sum of the plasma pre ure and the magnetic pressure can be integrated to yield

$$p_\perp + \frac{B}{8\pi} = \text{const} = \frac{B_0^2}{8\pi} \qquad (4)$$

where B_0 i the trength of the ma netic field ju t out ide the pla ma There exi t an infinite number of allowed olution to thi equation o that other circum tances uch as diffu ion will dictate the actual equilibrium olution in any given phy ical ca e

It is clear from Eq (4) that the pla ma pres ure can never exceed B /8− Thi value corre spond to a complete diamagnetic exclu ion of the magnetic field from the pla ma Other circum tance such as pla ma in tabilitie may impose additional limitation on the pla ma pre ure lead ing to values les than B_0 /8− A convenient repre entation of Eq (4) can be given in term of a parameter β which i defined as the ratio of pla ma pre sure to externally applied magnetic pres ure

$$\beta = \frac{p}{B_0^2/8\pi}$$

In terms of β Eq (4) be omes

$$\beta = \left[1 - \left(\frac{B}{B_0}\right)^2\right] < 1 \qquad (5)$$

The parameter β measures the effect which the pla ma can have on the applied field If $\beta < 1$ the applied field will be only slightly affected b the pre ence of the pla ma

Th diamagnetic effect of a pla ma ari e from per i tent electric currents flowing throu hout it vol ime In fact th magnetic confining force is just the body force $\mathbf{F} = \mathbf{J} \times \mathbf{B}$ But the e i tence of currents in the pla ma must imply a di ipat on of energy Thus unless maintained the confining urrents will decay with time so that plasma and magn tic field will gradually intermingle leading to e entual e cape of the pla ma Magnetic c n finement of a pla ma is therefore nece arily a tran ient proces with a time cale et by the lec trical conductivity of the pla ma Thi situation i analogou to the low penetration of a uddenly applied magnetic field into a large metallic con ductor The application of the field induce edd currents i i the surface of the cor ductor which de cay with time leading to the eventual penetrati n of the field

The effecti ene of a magnetic field in confining a hot pla ma for a long time depends on the elec trical re istivity of the pla ma This is gi en theo retically by the approximate expre ion

$$\rho \simeq \frac{{}^{-}6 \times 10\, Z}{T^{3/2}} \quad \text{ohm cm} \qquad (6)$$

where Z the mean ionic charge Theoretically ρ i ind pendent of den ity a result which cann t be xp cted to hold at very low pla ma den it es Not al o that pla ma has a negative temperature coeff c ent of re isti ity At 10 K a h drogenic pla ma ha a the etical resi tivity ab ut a low as pure c pper at room temperature and at tempera t res of 10 K or higher it i le

rd the r g of weak t magnet c field In the fir t St ll rat th drift w s can eled on th e ge by tw ting the t r into a figu e 8 Thu like the f m u M biu strip of m th m tic the in id wall o o e c rve b omes the ut de wall t the oppo te urve so th t n n t drift re ults

Adiabatic invariants Under the adi batic cond t n d fi ed by Eqs (11) and (12) th e om quantit es wh h a e approx m te con tants f the mot the so-called ad abat ar nts allud d to arl r These va ts are u eful in p ed ting m y of the deta l of pla ma b h vio and h e bee used a start ng p int f r erud t th or t cal analyses Th mple t of th se n a iant is μ th magnet moment as oc at d with the rotation a y ch rged pa t le magn tic field (s e MAGNETON) A mo g ch ge prese ts cu e t d a c rcl ng ch ge the efo e presents a c l r c rr t element w th wh ch s s c ated [polel k mag tic field imilar t th t of a mple loop c rre t. By analogy to Lenz law th s c nt loop alway di magnet that te ds to d p e fin t s mally the field t ength ns d the loop so th t n as mbly of ch ged p rticle pla m u lly e hibit a bulk d amag ti eff t ari ing from th e t mmat on of the ind v dual p rt cl diam gn ti eff ts

The m gnit d f μ g n by th e p s o

$$\mu = W \quad /B \qquad g/g \text{ us} \tag{17}$$

Th magnet mom t μ may be expect d t b c n t nt p ded the d ab t c dit o (11) a d (12) e f lfill d Mo e spe fically e mi at on f som th r t al w k gge t that x ept f r the effect f olli on the max mum fluctu t s μ r g a a p t le m ba k and fo th in a v y g magn t c field sh uld b ghly r p es tabl b the e pr ss

$$\left|\frac{\delta\mu}{\mu}\right| = ae^{-bt} \tag{18}$$

wh e d b a stant of o de 1 and t her 2 /λ f r pat ally ry ng fi ld o 1/ω f t m ry g fi ld It lea th t if 1 0 1 o les th fi t tio s μ sh ld b e ery small On ludes th t th e a many pl ma situations wh the c tan y f μ between part l ll n h ld b a alid as mpt o

Th al e f μ in plasma calc l t ns can be ll tr ted by s g it to lcul t the c d i fo r fl ct f a ch g d p rticle by a magn t m rro S ppo e that a piral ng pa ti le ap p a h magn tic m ror f m a g on wher th fi ld is B a d t to be refl t d wh t r he th po t M h e the fi ld inte t B_M F m (17) t t ee th t

$$\mu = \frac{W\ (O)}{B_O} = \frac{W\ (M)}{B_M} = \frac{W}{B_M} \tag{19}$$

Th t t p rt of th q t f ll w ce th e t gy es de t t tio l m r n t th p t f r flect It f ll w that th e d t n f flection at a po nt where the field B_M is

$$\frac{W\ (O)}{W} = \frac{B_O}{B_M} = \frac{1}{R} \tag{20}$$

where R i called the mirror rat o Thus s nce

$$\frac{W_\perp(O)}{W} = \frac{v\ ^2}{v^2} = \sin\ \theta \tag{21}$$

θ bei g the pitch angle f the hel x at $B = B_O$ the cond tion th t a particle be refle ted at or be f e it penetrate to M s ju t that the p tch angle hould be greater than a crit cal angle θ wh re

$$\sin\theta = \frac{1}{R^{1}} \tag{22}$$

This c ndit n is dep nde t of charge mass or total ene gy of the eflected p rticle except as lim ted by the equ ments of the adiab tic as umpt ns It is equally easy to sh w that in the eral ca e the pit h angle θ transforms in a co da ce with the elation h p

$$\sin\theta(u) = [R(u)]^{\prime} \quad s \quad \theta(O) \tag{23}$$

where $R(u) = B(u)/B(O)$ Equ t on (22) follows by tting $\theta(u) = \pi/2$ (reflecti n) Eq tion (23) r embl S ell s law f opti with $R^{\prime}$ play ng th rol of th i de of fr ction

R tu ing t the quest n of mag tic m r r reflecti n t i app t that if tw magnet mir r rs ar u ed e at each end of a w ker cent l fi ld the cha ged particles f plasma can b t apped in the magnetic bottle b tw the two m r pr vided th p ti le atisfy th p tch ngle q em nts Thi s the mi r machine If a pl sma onta particles w th d mly i ented p tch gle we e t be suddenly th ust int a magnetic fi ttle ll p t l w th p tch gles less th n θ w uld mmed at ly cape Th m inder f the part cles would be tr pp d how er i depe de t f the charg ma energy and could e pe only as m tual c llis d fle ted them nt u fa r bl p tch angl At high t mpe t th pro e i p dicted to be q te slow

Anothe con eq en f the co ta cy of μ r lat t plasma heati g by m gnet c comp ession It ha l ady been point d ut that an crea ng magnetic fi ld w ll c mpres a plasma wh ch t ds to ma ntain con t nt flux th ough ts vol me Th pr perty also tru for the flux th ead ng e ch orb t Sin $\mu = W\ /B =$ nstant and $\sim (1/B)\ W\ ^{/2}$ th implies th t $B_r \sim W\ /B =$ co tant, th t is th flu th ough the orb t circle ar a π B is c sta t Th heat effect follows s mply by n t g that sin e μ i on tant W mu t increa in d e t p op rt n to B This s th p e s f adiab t c mp e heat ng often lluded t n th l teratur

To mpl te the li t f d ab ti i r nt f pl ma m t two m w ll b menti ned Sup se th t th pl ma p rt cle ar tr pped n magnet c bottle d m e in pe d way ba k

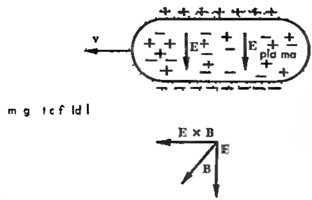


Fig 4 Schematic illustration of drift of a plasma across a magnetic field in vacuum

slight separation of charges (Fig 4) is all that is required to generate an internal polarization electric field in the plasma which maintains the velocity However if the plasma passes into a strongly conducting region (another plasma) the polarization fields would not persist and the motion would stop the momentum being taken up by the magnetic field or converted into rotation

In another case if a plasma is immersed in a magnetic field which is then increased slowly induction electric fields will appear which will cause the plasma to be compressed toward the magnetic symmetry axis of the system (where E = 0) In a uniform magnetic field of circular cross section this would result in a uniform radial compression of the plasma Throughout the process the flux through the plasma would remain constant (ignoring diffusion effects)

These illustrations point up the importance of the E × B drift velocity Any situation in which electric fields appear in the plasma because of induction effects or separation will produce this drift In some cases drifts of this kind can be self perpetuating (charge separation leading to a drift leading to more charge separation and so on) so that a plasma instability results In other cases the E × B drift is accompanied by plasma heating as in the example of the magnetic compression given earlier

If the magnetic field in which the plasma particles move is inhomogeneous other drift motions occur If there is a gradient of the magnetic field strength perpendicular to the direction of the field the radius of curvature of each particle will clearly be smaller on the high field side of its orbit than on the low field side and a slow transverse drift perpendicular to the directions of both ∇B and B will occur Since oppositely charged particles spiral in opposite directions this drift will be oppositely directed for electrons and positive ions so that it produces a tendency for charge separation to occur The magnitude of the drift is given by

$$v_b = \frac{r v_\perp}{2}\left(\frac{\nabla_\perp B}{B}\right) \qquad (14)$$

As the charged particles move in helical paths along the magnetic lines of force they may encounter regions where the flux tubes (bundles of magnetic lines) are curved While the particles are being guided around these curves by the magnetic field centrifugal forces will arise which will produce a drift The centrifugal drift is also oppositely directed for ions and electrons and has the magnitude

$$v_c = v_\parallel^2 /R\omega \qquad (15)$$

where $v_\parallel$ is the velocity of motion of the particle along the lines of force and R is the local radius of curvature of the magnetic lines

The centrifugal drift v_c is an example of a more general gyroscopic kind of drift that can be expected to arise in situations where the plasma particles are subjected to a force which is perpendicular to the local field direction Another example is the drift velocity v_g which will occur in the presence of a gravitational field The magnitude of this drift velocity is

$$v_g = g_\perp/\omega \qquad (16)$$

where $g_\perp$ is the component of gravity perpendicular to the magnetic field In strong magnetic fields v_g is very small but it may play a role in geophysical phenomena in the upper atmosphere

It is essentially impossible to study a confined plasma in the laboratory without encountering magnetic field gradients and therefore stimulating the drifts v_b or v_c Since either of these drifts can give rise to charge separation effects unless care is taken in choice of the field configuration electrostatic fields within the plasma can be set up which will cause the E × B drift v to occur leading to a rapid escape of the plasma A classic example is the simple torus with magnetic field lines parallel to the torus walls as shown in Fig 5 This geometry the forerunner of the Stellarator is characterized by a magnetic gradient which is everywhere inwardly directed (the field at the inner wall of a simple torus is always stronger than at the outer wall since the line integral $\oint B \cdot dl$ is the same for all paths taken around the inside of the torus) Thus if a plasma is confined in a simple torus upward and downward drift motions will tend to occur as predicted by producing a vertically directed electric field and a subsequent common outward drift of the plasma toward the outer wall that i

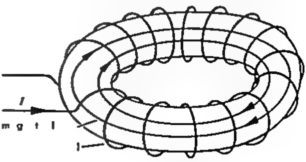


Fig 5 Magnetic field l ... simple to

r th e The Alf n wa e vel c ty is i e pre

$$v_A = \sqrt{B^2/4\pi\rho} \quad m/ \qquad (25)$$

the pla a den ity p s i al d ly for frequenc es l lo l of B a d p uch th t $v_A \ll c$ l /8 $\ll$ ½ρc (m on tic n rgy de ty npa ed w th o e half the m energy

quenc e n the icinity of (ii) e onan e a e m t n with the n cyclot on fre- icc d th wa es bec m h hly d

j nc e b twe ( ) and (iv) w e prop- ll ed nl f p cial d cti ns of : n w th re pect t th magn t field and w e prop g t d which e emble the nd e tr rd ry l ght wa n bire y tal Se CRYSTAL OPTICS

freq e cy (v) the pl ma p pagat l ctr m g et c wa w th a pha el c ty th n th t t beh es lik a m dium i de of f ct n les than n ty The l ct o i gi e by

$$= \sqrt{1 - (\omega/\omega)} \qquad \omega > \omega \qquad (26)$$

p p rty f a pl m n be u d t dete elect n d n ty By mea m$_e$ the pl a the t m f a m cr wa b m pr p- th gh th pl m th m n inde of a b det rm ed d fr m th s the d n r ugh u f Eq (26) The num l al e la m f quency giv n by

$$f = \frac{\omega}{2\pi} = 9 \times 10^3(\ )^{\prime} \qquad (27)$$

d n ty f 10 lectr / m $f = 9 \times$? o d g t f e pa wa el ngth mm

pla m f q y t lf epr nt a l s- mple f coope ati ffects n a pl ma It t a nat l f que y f llat of th s f th pla m c r g e n the b- f y m g et fi ld It ar e fr m th f ct iny net d pl c m t f the pl m ele tr p ct t the ion pr d e p l i at n fi ld wh l t a e to ng f Th h a d pl c me t o ur ol m llat n le t ab t th p t f h g r ll lt Th i be g m h m re mas- w ll r ma es t lly t t o ary l ke pl n p dd g If m d t led ly i p ed t he h n th t th ffe t f th th loc ty f the l i t m d fy l ghtl ll w d f eq y f th ele tr st t c pla m llati th t a d p s el t lt a f q) wa l ngth r l t h p how th t h sc ll t s n c r abo t bo ded th l w fr q ncy de by ω istab l t es Th t b l t exh b ted n m pe h p t m t n nd te p perty sotr p i th rm l pl ma w th ma w ll s

particle di tribution uld n t exhib t any insta bil ty Howe er ll pl mas c n ted in th labora to y d ff in some espect f m such an ideal pl ma p es i g a h gher degree of order and th a l we state of entropy This difference i entropy m k t th rm dyn m cally po ible f r instabil ty o turbul n e to occur wh ch crea s the ent opy by int ducing a greater d or f d o der In a magnet c lly confined pla ma n tabil ities usu lly result in the r p d e cape of the pl sma A imple le for th theo etical gr wth time of many pla ma stabil t e i s mply to divide th o er ll dimens o s of the pl sma by the thermal elo ty f the i This i ally a e y short time f r hot pla ma be ng f the der of few m crose ds Und rstand ng and ntrolli g pla ma n tab l t e clearly prim t get of h gh temp r ture pl ma re ea ch

On n w d sti gu hes tw gen ral la es of pl ma t l l t es (i) configurat on p ce in stab l t e i wh h the nstab l ty a b su f ord in nfigu ation spa (pr re g adi ents magnetic fi ld rvat re and so f th) and ( ) elocity sp c tab liti i ng fr m rd r ng n el ity pa (stream ng m t on rder d dep tur fr m a m xwellian elo ty d t ib t on a d f rth) Th hyd om gnetic i t bil t es r p- re ent the ma figu ti n p in tab l ties S ch tab lit s m y o r f there e ts an ener getic lly f or d i t rch ng n flow f th plasma d the nfin ng mag et fi ld which w ll llow the pl m t exp nd

Wh n tream n$_g$ mot o of y ub t nt l f ac tion f th pa ti l f a pl ma ccu s whe he vy l t i cu e t i b g c r ed by the lec tr n (th p nch eff ct) n de ome ond ti it i p s ble f an p n ti lly growi g d sturb- ance t o cu draw ng t e gy from the rder d m ti n of the t eam Th f m l r n tab l ty of fi e ho e ha a cl e nalogy in a pl ma to c t one f lex mpl

Anoth typ f el c ty pa e tab l ty whi h w ld fe d n a n nt i te ct o betw n elec t on pl ma sc ll t s in a m g et c field and the d d nergy f n n ot p ele tron el c ty d tr b t n ha been theo t lly pred ted A suffic t c ndit n fo th pla ma t b tabl aga n t h n table o cillat s that

$$(\omega/\omega\ ) < 1 \qquad (28)$$

th t i th pla m freq i n y should b l ss than th el tron y lotron freque y The c nd t on c n als b w tten f m the defi i of th qu nt ti s s qui l nt t the c nd ti n

$$(\ m\ )/2(B/8\pi) < 1 \qquad (\ 9)$$

that i the m s nergy den ty f the ele t ns m t b les tha twe c th ergy d n ty f the m g t c field Aga t can b re rang d so s t defin t l β alu f th elect p e n nt

$$\beta = p/(B/8\pi) = n\,kT/(B/8\pi) \qquad (30)$$

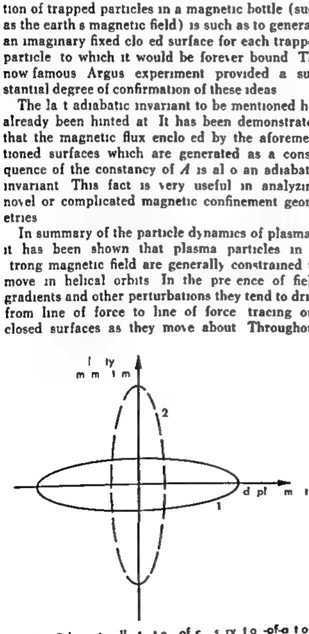
and forth between limits (as in the mirror machine) It can then be shown that the o called action integral is an adiabatic invariant The integral is ju t the line integral of the momentum component parallel to the direction of the field taken along the path of the guiding center that is

$$\oint p_{\parallel}\, du = A = \text{const} \qquad (24)$$

The action integral has the dimensions of an area in $p_{\parallel}$ u (pha e) space Its constancy implies that this area is a constant Physically it simply means that as a trapped particle moves about in the confinement volume its guiding center motion must always be such as to keep the phase pace area constant (Liouville s theorem *see* STATISTICAL MECHANICS) If axial compression occurs this implies that the axial momentum must increase correspondingly (ee Fig 6) One of the important results of adiabatic theory is to show that the constancy of A implies that in the absence of collisions and for slowly varying fields the drift motion of trapped particles in a magnetic bottle (such as the earth s magnetic field) is such as to generate an imaginary fixed clo ed surface for each trapped particle to which it would be forever bound The now famous Argus experiment provided a substantial degree of confirmation of these ideas

The la t adiabatic invariant to be mentioned has already been hinted at It has been demonstrated that the magnetic flux enclo ed by the aforementioned surfaces which are generated as a consequence of the constancy of A is al o an adiabatic invariant This fact is very useful in analyzing novel or complicated magnetic confinement geometries

In summary of the particle dynamics of plasmas it has been shown that plasma particles in a trong magnetic field are generally constrained to move in helical orbits In the pre ence of field gradients and other perturbations they tend to drift from line of force to line of force tracing out closed surfaces as they move about Throughout



Fg 6 Schemat c ll t t o of c s rv t o -of-a t o teg al Eq (24)

the motion of the plasma particle the collective motion will be con trained to be such as to pre erve near equality of total po itive and negati e charge ince any departure from neutrality give rise to strong electric restoring forces

Confinement criteria With the e fact in mind the problem of magnetic confinement may now be stated in detail

1 To immerse an electrically neutral pla ma in a magnetic field sufficiently strong that all particle orbits have diameters small compared with the dimensions of the confinement chamber This in sures that the particles cannot at once touch the chamber walls

2 To find a configuration of ma netic field which prevents the rapid escape of the pla ma along the magnetic line and yet does not introduce uncanceled drift motions which would cau e it to strike the chamber wall This require either that the lines of force shall clo e on them elve (a in the pinch effect or the Stellarator) or that omething akin to the magnetic mirror effect be u ed

3 To ensure that the pla ma can be u tained in a state of table pre ure equilibrium by the magnetic field either by u e of very trong field pecial field configuration or special pla ma conditions

The last mentioned problem is potentially the most difficult one and will be referred to again in the di cussion of pla ma in tabilities

WAVES AND INSTABILITIES IN PLASMAS

Because of the coupled nature of the motion of plasma and its electromagnetic field en ironment it can support unusual oscillatory or wa e motion both stable and unstable

Stable wave motions A rough ubdi i ion of tl e stable wave motions is po ible in terms of four characteri tic frequencies or periods of a pla ma a sumed immer ed in a magnetic field In many typical ca es the e characteri tic frequencies occur in the following order (i) Interparticle colli i n frequencies (lowe t) (ii) Ion cyclotron frequency (iii) Electron cyclotron frequenc (iv) The pla ma frequency $= \sqrt{4\pi ne^2/m}$ (h gh e t) Only a few of the features of wa e propagation will be sketched the detail of pla ma wa e propagation being remarkably complicated The reader i referred to the now oluminou l terature in the ubject for further detail

At frequencie below (i) a pla ma would beha e a an ordinary gas and propagate a imple ela tic wa e Su h wave wo ld be imp rtant only for high den ity low temperature or large pla ma

At freq encies between (i) and (ii) a character i tic pla ma wa e the hydromagnetic or Alf en wave i p ible Thi wave re embl le that which would be propagated by a l aded ela t c string Here tl e tri g are the magnetic line f f rce l aded by the pla ma ma (that i primaril the i n) Sati fying the ad al ati criteria part cles a d field di t rt t gether (field line t ck to tl e pla m and ice er a) pr id loaded ela ti

tually in p rati the pla ma d ffus ng lik an or d ary g s O the other hand n the second xam pl the t m s a e ery lo g c mpa ed w th ycl ion per od f r a o abl m g eti field tre gths a d i l ly vary g fi lds the adi b tic a s mp t n o ld b well at f ed Further ncreas in the temperat e o magn ti field trength would mak th dit o s en m re accu ately sat sfied

Degrees of freedom Anoth r intere t ng co se que e f pla ma s tu tions wher th olli i n t mes a e l ng that f ope ti ns pe f rmed n th pla ma i t mes hort ompa ed w th the c ll i n t mes the degree of fr ed m f the plasm m t n a esse t lly uncoupled That is to ay mpr ns pe pe d ul r to th field di ecti n n lve only the ot tion l de r e of f eedom o that th pl m a t a tw d me n l ga S mi la l compre o alo g the fi ld li e re ults in th pl m acting s d mens onal g The l of th rm dynam c l t the v lue of the ad bati ga co ta t γ to the number f degree f freed m f $\gamma = (2+f)/f$ Th s f r omp e si n tr n t B $f = 2$ s th t $\gamma = 2$ F r l ngitud l c mp es n $\gamma = 3$ Th ame g ne al thermo-dyn m laws sh w th t th t mper tu e s parti cle de ty law f a d abat comp es of a g s is th t

$$T \propto \gamma \qquad (37)$$

Th s f t a r e mp es $T \propto n$ b t for l ng tud al omp e $T \propto$ that i T a e th quare of the mp ess ratio B t if th compres on we e c ed t a t me lo g c m p red with oll i tim s $f = 3$ $\gamma = 5/3$ (all de-g ee f freed m coupl d) d $T \propto$ / a ub ta t lly l p o u ed a t w th d ns t

Dynamical friction Wh l oll ion between an rg t c i a d the el tron f a pla m le d t l l d ffect o f th o a path w g to the sm ll ma of th ele tr n th imp ta t f fect, dynam l f i t a ar e Pr id d nly that th m n en gy f th ion *great r th* th t f th l ct the tat sti lly e aged ffect f e ll ns ith l t ns w th th Debye l gth l d to f t l dr g o the i n wh ch w ll e l lly r d c m rgy t th t f th lect ns Th h an mpo ta t eff t le d g t a damp g f th e gy f ene g ti io m m sed c ld pl ma On the othe h d if th m a rgy fo than th t f the el t the elect ll ons w ll l d t an f th gy by h t g Th l tt ffe t mport t ca s wh pl ma h ti g s m pl hed h t g th lect t s joul t eh t ng

4 gl n a b d ed wh h p e sent both these effect Th

$$\left(\frac{dW}{dt}\right) = 4\sqrt{2}\,1 \quad \frac{Z}{(\pi m k T)^{1/2}} \frac{m}{M}\left(1 - \frac{W}{3kT/2}\right) \qquad (38)$$

F n g m ll comp ed with the m lect n rgy the r te of i n h t ng (T i ev) is gi en by

$$\left(\frac{dW}{dt}\right)_m = 8.8 \times 10^{-8} \frac{Z^2}{A} \frac{n}{T^{1/2}} \quad e /sec \qquad W \ll 3kT/2 \qquad (39)$$

When the i n energy is substanti lly greater than th me n ele t on energy th ge eral xpres io take the form

$$\frac{1}{W}\frac{dW}{dt} = -5.7 \times 10^{-8} \frac{n_e Z^2/A}{T^{3/2}} \quad sec^{-1} \qquad W \gg T \qquad (40)$$

This can be integrated to yield an exp e si n for the xpo ent al decay of ion energy as a function f time

$$W = W e^{-t/\tau} \qquad (41)$$

$$\text{whe e} \quad \tau = 1.8 \times 10\,(T^{3/2}/n)\,(A/Z^2) \qquad (42)$$

If the le tr n temp r tu e is low t m y be qu te m ll omp red with the mean ion i n colli s o time a d ther f e will dominate the energy xcha ge t mes fo h gh en rgy i n F r x mple if $= 10$ cm and $T = 10$ e then for ene get c prot $\tau \sim 5.5$ μsec By contrast if the p to e e gy f r e mple 10 ke the orre pond ing i n on ce tte ng t me calc lated fr m Eq (36) r ughly 6 msec o 1000 t mes l rg r At n le tron t mp rat e of 1 ke h w e the tw time bec me al t q al

Th e p s i fo τ h ld as lo g a the n elo ty le than th me n elo ity f the elec t o s that is s l ng s

$$W < (M/m)\,{}^3\!/_2 kT \qquad (43)$$

Wh th s i ot s t fi d th dyn m c l frict on rate mewh t mall r than that j st pred t d F p ton th oc u s wh n $W = 2760\,kT$ that is nly at r h gh nerg es

The enti e q ti n of e gy t ansfe r tes be twe n on nd el t o s s ne of g t importa ce i pla m a ch i ce m y c se the e te a crt al n d term ing the elat mp rtanc of oth pr ce h a the r te of lo f en gy from the pl ma by r d t n (wh h f om th ele t n) B t s f th w ing lm t n xp ime t l data t n the fundament l proc ses

RADIATION FROM PLASMAS

R di t n p des a d e t c l ng me h m f r a h gh t mpe tu pla ma F tunat ly nd ed f r the f t re of pl ma r h the ry h ws th t at en th h gh t p ti le d n ti s u ed n th lab t y the r d ti rates f m a pla ma m h le s th th Plan k bla k b dy alu F x mple t a d t n temp r ture of 10 k th Pl n k r d ati be ng p p t o al to T w M m unt t the alm t i once i abl v l e of 6×10 watt /cm (e HEAT RADIATION) But th f rtu t fa t that te uo pl m i opt lly ry thi o er lm st ll of t mis io p ct m

Thus

$$\beta < 2(kT/mc^2) < 2(T/511\ \text{kev}) \qquad (31)$$

if T is measured in kev This is a fairly stringent condition especially at low electron energies If one still further manipulates the condition it can be shown to be equivalent to the requirement that

$$(r/\lambda_D) < 1 \qquad (32)$$

that is the mean gyromagnetic radius r of the electrons should be less than the Debye length It has already been pointed out that cooperative effects cannot occur within distances shorter than a Debye length so this condition is by no means surprising

In concluding the discussion of instabilities it is important to recognize that at the time of this writing only the grossest features of the theory of plasma instabilities have been corroborated experimentally Since the question of plasma instability is the greatest potential barrier to effective magnetic confinement the study of instabilities must proceed much farther before even the feasibility of long time confinement is demonstrated

COLLISION PROCESSES IN PLASMAS

In the absence of instability mechanisms which could destroy a state of order in a plasma the drive toward a state of higher disorder comes about through interparticle collisions The dominant interparticle collision process in a high temperature plasma is Rutherford scattering elastic scattering arising from the mutual Coulomb electrostatic fields of the charged particles of the plasma Such processes lead to the deflection of and energy exchange between the plasma particles These collision processes are important since they determine *the basic rate of all collisional transport processes* in the plasma The cross section or effective collisional area σ for close collisions between plasma particles of equal mass and charge can be simply estimated from the classical minimum distance of approach of two equal charges (where mutual potential energy becomes just equal to initial kinetic energy that is $Z e^2/r_{\text{mi}} = W$)

$$\sigma = -Z e/W \quad \text{cm} \qquad (33)$$

However if the classical minimum distance of approach is compared with the value of the Debye length λ_D given in the table it will be readily seen that at the usual particle energies λ_D is typically some 10^9 times larger Thus the probability of a particle colliding with some particle that is distant yet still within the range λ_D is some 10^{18} times larger than that it should make a simple hard close collision Thus even though the effect of each individual distant encounter (within λ_D) is infinitesimal the statistical sum of their effects is not and in fact is about 10 times more important than that of close collisions In the calculation of this effect the logarithm of the ratio $(\lambda_D/r_{\text{mi}}) = \Lambda$ appears $\ln \Lambda \cong 20$ in most cases One finds for an approximate value of the scattering cross section owing to distant collisions the value

$$\sigma_d \cong (-Z^4 e/W)(\ln \Lambda/2) \qquad (34)$$

Written in terms of the particle energy in ev this becomes

$$\sigma_d \cong 10\sigma \cong 6 \times 10^{\ \ }(Z/W) \quad \text{cm} \qquad (35)$$

where W is in ev

Some quantitative values are of interest If $Z = 1$ (hydrogen ions or singly charged heavier ions) and if $W = 1$ ev then $\sigma_d \cong 6 \times 10^{13}$ cm^2 or some 10 to 10 times normal atomic or gas kinetic cross sections However if $W = 1$ kev σ_d is 10^6 times smaller (almost 6×10^{-9} cm^2) and is already much much smaller than atomic cross sections It can be seen that even disregarding the fourth power dependence on Z the range of collision cross sections encountered in hot plasmas may be enormous It follows that the collision mean free path d can vary over an even more extreme range considering the range of densities which is of interest For example for a hydrogenic plasma density of $10^{\ 7}$ cm (about the upper limit for most high temperature plasma studies) and a mean ion energy of 10 ev $d = 1/n\sigma_d \cong 1\ 6 \times 10^{-4}$ cm whereas at $n = 10^{12}$ cm^{3} and 1 kev $d \cong 16$ km Clearly the physical behavior of the plasma can be expected to be quite different over ranges of temperature and density which may be encountered in even a single experiment *See* SCATTERING EXPERIMENTS ATOMIC AND MOLECULAR

Relaxation time The collision processes in a plasma serve to define the rate of randomization of the energy and direction of motion of the plasma particles One reason that these processes are important is that they act in opposition to magnetic *confinement (especially in the mirror machine)* and set an upper limit on its duration From fundamental work by S Chandrasekhar and Spitzer the so called relaxation time for a large angular deflection or for energy exchange comparable with the original energy of a given ion (or electron) colliding with particles of the same kind can be calculated To a sufficient approximation this time is given by

$$= 5\ 7 \times 10\ (A^{1/}/Z)(W^{/2}/n) \quad \text{sec} \qquad (36)$$

where W is in ev

Returning to the numerical examples given in this case one has for protons ($A = Z = 1$) at a density of 10 cm^{3} and an energy of 10 ev $\tau = 1\ 8 \times 10^{10}$ sec while for electrons ($A = 1/1836$) $\tau = 4 \times 10^{-11}$ sec which is a very short time indeed On the other hand at $n = 10^{\ 3}$ cm^{3} and energy of 1 kev the times become equal to 18 msec and 0 42 msec respectively It is quite clear that in the first example in the times are small even compared with the cyclotron frequencies of the plasma particles (normally the shortest characteristic time in a magnetically confined plasma) so that heating by magnetic compression would be light and magnetic conf uld be even

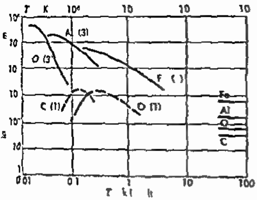


Fig 8 R t f two imp rt t pl mo d t m h t mp r t f m ol m m oxyg n d b

f at m b ga t the o d ry hyd oge c b m t ahl ng t The f t that mm d tely pp ent f om th c rve th t t tempe t es f rde 10^6 K the x t ti r d at n r te en rm mpa ed w th d ary b m tr h l g Th ad t ll m tted in th va uum h a l t eg o of th p trum $\lambda \cong 100$–1000 Å O ly a th t mpe at re r che 10 K or m doe it d p t m rea on ble al s Th h w that the lo t mper ture e t t r d ati n m y p de a v y r p d e ol ng j e f h d g pl m n w th el tr ly m ll pe e tag f i p rti e Sec ndly t pp t th t n e h gh temp r tu e r hed the t l ll t b t th d ry b m trahl g al e (d at d by the mark d li e al ng th r ght dg f the pl t)

Th p ed lculat o pr e t teady tat ates H wever in expe im nt l plasm s the d t f the exp m t may be t o h t f th pla ma i t r ch th t dy st t d g ee f tr pp g In th ca al l t ns how th t the d t at m v l b t t lly high th th t t d t d

At l t ly l w pl ma t mp at d y h gh mp r ty d t ll b pt n of th a d n m he mp tant d ed e th l ul ed l m h t Th u lly c r ly t r rv high bsol t ad at fl x h w e n e th nse l self b pt gnal the pp a h t m l b um r P) n k r d at n levels

Other mechanisms Th mech m des b l th l r od c th r man r dat o fl n th x y d th m ltr l t p rt f the p c t m Co g t rd l g wa le gth th t g t d t n r g n n t rea hed til th lo g wa nfr d th h rt w l gth m g t th d In th g n th pl m g po sesses m ha m wh h an pr d p t eci ll al t fl fl l m t d l y th fl lengh l an l (h t h es th qu of f eq y) th l g w l ngth r d t n doe t mp se app ec H rgy l mech m x pt at th h h t lect t mper t Th

diation t th n t mportant ly f r a plasma mmersed t a trong magnetic field It ari es sim ply f om the ntrifu l acc le ation of the el c tr n s they m ve in helical o b ts in the ma n t c field Measurem nt of this r diation pr des an other po ible way to determ e the elect on tem p rat r f the plasm by pplying techni jue m lar to th empl yed in rad astronomy [R F P]

Bibl g aphy H Alfve *Cosmical El trody namics* 1950 S C Br wn *Basic D ta of Plasma Phy ics* 1959 R F Po t Controlled f io re earch—an pplicati n of the pl ys s of h gh t m p r tur pla m *Rev Mode n Phys* 338-362 19 6 R F P t Fus on p wer *S i Am rica* 197(6) 73-84 1957 L Spit J *Physics f Fully I ed G es* 19 6 U ted N tion *Proc S c d I te C J P ceful Uses Atom c En rgy* ol 31-32 1958

Plasmal

Th e aldehydi mp nents f lip ds which giv iti e c lor t sts with eage t u ed fo det ct ng ld hyd s in tissi s The F ulg n test f r pl s malogen depe d on the l be tion of pl m l p i ip lly palm taldel yde nd tearald hyd f om th s lip ds by the action of mer ur c chlo r de a d et c a d *Se* LIPID PHOSPHATIDE [H E C R H C]

Plasmodroma

In om t om c sy t ms th s t a ibphylum of P to including th M st g pho Sa cod a d Sp o The C l ta ar exclud d Lo om t r o gan lle if pre nt m y be flagell r p e do p dia but not c l a Th r s no ucle r dimo ph sm l ke the m cr nucl us d m r nucl us s s n n typ cal c liate The ubphylum Plasm d oma i n t r ized as s bd i n f Pr t o by e t m d rn tax om sts [R P H]

Plaster

A pl st e mi tu f l d a d water wh h t t a hard her t ol d and wh h s used to li e the t t ro s f b ld ng A im la mate al f d ffe t comp sit n ed t line th exte rs f b ld gs i k own tu o Th term pl te s l o ed n th d try t d ignat pla t f p r s Pla t r i u lly appl ed in o e o mo h (ough or sc at h) c at up to ⅜ in th ck a d als a m th wh te fin h co t b ut ⅛ in th k The s l d i th ba e c ats e hydrat d (r l k d) l me and fib r rll r (f l nd ng) and p rtla d em nt (the l t m y be m tted n me pl ste) The fi sh e t cons ts of hydr te l l m d gyp um pla ter (n add ti t th wate) *Se* LIME (INDU TRIAL) MORTAR PLASTER OF PARIS [M C M]

Plaster of paris

Th h m hyd ate f alci m sulfat ($CaSO_4 \cdot \frac{1}{2}H_2O$) m de by l i g th m al gyp um ($CaSO_4 \cdot 2H_2O$) at t mpe tu e p t 2 0 C It ed f mak ng pl t m ld and m d l F r a

means that as one might expect from Kirchhoff s law radiation is greatly reduced compared with the Planck value so that under the proper circum stances a plasma with a kinetic temperature of 10 K might radiate at a rate equivalent to the ra diation rate from a black body at radiation temper atures of only a few hundred degrees K Neverthe less *in many experiments great care must be taken* to avoid certain impurity problems u as to keep the radiation from rising to a value where it would overwhelm the means for heating the plasma and keeping it hot

Common mechanisms Considering collisional proces es there exist three important mechanisms for radiation from a pla ma

The fir t is the generation of x rays (brems *strahlung) which occurs when the plasma elec* trons are deflected by encounters with the ions (*see* BREMSSTRAHLUNG) The second mechani m is a similar radiation which occurs when electron elec tron collisions occur This proce s is important only at very high electron temperature where the electron motion becomes relativistic (T of order mc = 511 kev) The third mechanism which can occur and one which under some circumstances may overwhelmingly dominate the radiation losses is that proce s which might be called excitation ra diation radiation resulting from the collision of electrons with partially stripped ions (ions with re maining bound electrons) with the production of excited states of the bound electrons and subse quent radiation Electron ion bremsstrahlung can be calculated by the methods of quantum mechan ics from which one finds for a maxwellian distri bution the approximate expre ion for the radia tion per unit volume

$$p = 1\ 4 \times 10^{-}\ n\ n_i Z\ T\ ^{/} \quad \text{watt/cm} \tag{44}$$

Here Z is the ionic charge and T is measured in degrees Kel in kinetic temperature Except at high densities the radiation rate is nominal being only some 14 mill watts/cm f r a hydrogenic plasma at 10 K and a den ity of 10 /cm (Z = 1 $n = n$) At n = 10 /cm this would be 10 times larger reaching the respectable figure of 14 kilowatts/cm Also for a plasma compo ed entirely of higher Z ions since electrical neutrality of the pla ma requires that $n = Zn$ the brem trahlung radiation rate varies as Z and would therefore be much larger

Excitation radiation rates can be calculated if the degree of stripping of the ions in the plasma is known In the past it ha been cu tomary to as sume that by the time kinetic temperatu e of 10 – 10 K or higher have been reached all at m in a *plasma* will have been completely tripped of the r bound electrons In this ca e there would of cour e be no excitation radiation emitted The a sumption of complete tripping would be alid for a hydrogenic plasma who e atoms ha e o ly a in gle easily tripped electron Unf rtunately it is not po sil le to create in the laboratory an ab o lutely pure hydrogen plasma there will always ex

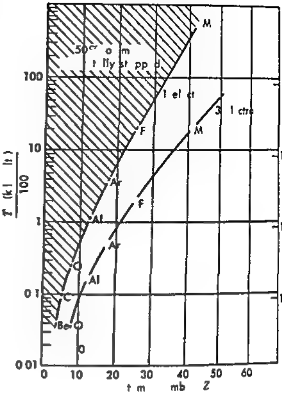


Fig 7 Stripping curv

ist ome appreciable number of higher Z contam ment atoms such as oxygen

By means of calculations imilar to tho e em ployed by a trophysicists in calculating the radia tion from the sun s corona one can compute the degree of stripping of impurity atoms immer ed in a low Z plasma It is found that the degree of stripping is much less than one would have intui tively as umed As a result the role of exc tati n radiation can be ery important e en at quite h gh kinetic temperatures

In the calculations it is found that the mo t in tere ting and hardy ions are tho e which are stripped down to one to three or f ur remaining electrons Using approximate ionization cro ec tions a tripping curve has been calculated f r the expected relative abundances of one electron (hy drogenlike) and three electron (lithiumlike) i n as a function of atomic number and kinetic tem perature (Fig 7) The figure how loci for the curve di ding the region of temperature below which a given atom has one or more bou nd elec tron and for a imilar curve for three or m re bound electron These cur es repre ent tead tate values of the stripping It will be een that high Z impurity atoms become completely tripped only at very h gh temperat re

U ing calculation of th ki d one can deter mine the expected rate of excitati n radi ti n per impurity atom a a functi n of kinetic tempera ture Thi sh ild l e d e f r all exi ting tate to obtain the total ra liation rate H wever it i f ficiently inf rmati e to pre ent the re ilt f r the tw tate (one electr n and three ele tron) t gi en Th re ilt of the e calculati n t ing ap pr xim te excitati n cr re pre ented i Fig 8 Th re lt ar an a

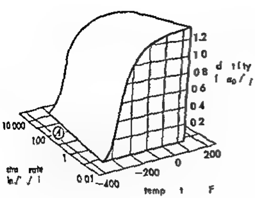
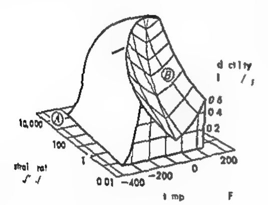


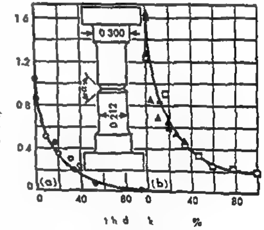
Fig 2 D tlty f l d mld t l n t l te t a f nct f t mp t d t t p d M tal f rtually gl b ttl t l w t mp t d h gh tr t (g A) (F m T T h d W M B ld J W D R b rt d St s Co C k g d Emb ltl m t W l y 1956)



Fg 3 D ctlty t l d mld te l h g d w th hyd g f ct n f t mp t d t t p d P of hyd g h dep d th d tlty f th st f g B B ttl s g n A t wh th hyd g t o t (F m T Toh o d W M B ldw J W D R b t d St C C k g d Emb ttl m t W l y 1956)

t p u the N th Atl tic in Janu ry 1955) D sol ed mp t wh h d ff th ugh o h w some m b l ty the h t met l w ll ff t the d t l ty f the h t m t l t n ng f tempe at d d f rm t tes If by a s t ble h f t mpe t re the m b lity of th m P ty be ha g d o th t ts l e t me m l p po t n t d f rm t n rat th m m t of th h t m t l t m g t m ke p th d f rmat n mech m m v well b h m p ed and b ttl w ll e ult F g re 3 h w f mpl h w teel e t n g h d g d s- ple b tl n r e t temperatu nd d f rm t ges (reg B f Fig 3) Th t d l t to th l w t mp r t b ttl es wh h teel pos es heth r the ta hyd g nt (g n A f Figs 2 d 3)

N t b th f f h les w th m t l pec men d t n will ffect th d t lit n tw w ys They will l wer the ge er l level of du til ty of all m tal a d they w ll h ft the cliff which bounds the low temper t re br ttle r nge f Fig 2 to h gher tempe tu es and lowe strain r tes B th f the effect bec me greater as the re of oss e tion occup ed by the notches or h les be mes l rger (Fig 4) and both of these effects (for a g en p p tion of the cr ss section oc up d by n tches o h les) w ll ary in intens ty from metal to metal These con id rat ns are im p rtant be au e a gi en steel when tested as a smo th bar in a imple t n on te t may be quite ductile and yet when fabr ated into a machine part ontain notches hol s may be danger ou ly b ttle Th embrittling effe ts of bl w h les fr m improper casting or id introduced by im pe n eali (f e mpl the hydrog n an neal g of oxyg n l ari c pper) stem from th same c se Und olved impurit es whose hard e se a e ma k dly diffe t f om that of the host m tal (ther hard ofte) are mbrittling be- cause they effect ely beh as h les (discontinui ti s) in the m tri In a mil e brittle ski s put metal int ntion lly (c rbur ed or nitrided a e put n ste l o chr m m and c pper pl t s) o un ntenti ally (oxyge n nitrog h su f in tit ni m nne led in air) will em b ittle the b e met l At th sl ghtest def rmat n



ON t h l d t f SAE 1020 t l (l p t d ctlty w th 60 tch Upp d f rt l l p ts d tlty w h 90 tch L w d p d ctlty w th 30 t h)
● Dat f b d SAE 1020 t l
▲ tch t l t d f pp
◻ d f hyd g -emb ttl d pp

Fg 4 D ctlty f ( ) n al d mld st l nd (b) pp a a f ct f the p t g f ct l p p d by a t h f th typ h w i the k t h (p ymbol) f t f th p rc tag f s-se t o l p d lly b ttle k (fll d ymb l) (F m G W m d W M B ldw J Th Eff f B ttl Sk th D tlty F M t l Am S T st g M t l P e- t 79 1956)

description of the casting method of ceramic forming, see CERAMIC TECHNOLOGY.

When the powdered hemihydrate is mixed with water to form a paste or slurry, the calcining reaction is reversed and a solid mass of interlocking gypsum crystals with moderate strength is formed. Upon setting there is very little, if any, dimensional change, making the material suitable for accurate molds and models.

The chemical reaction of hydration requires 18.6 lb of water for each 100 lb of plaster of paris; any excess of water over this makes the mixture more fluid and it eventually evaporates, leaving a porous structure. In general, the greater the porosity, the lower the strength of the set plaster. Plaster of paris molds for ceramic casting must have a certain minimum porosity in order to absorb water from the slip; thus for this application the amount of water added represents a compromise between the conflicting properties of high strength and high porosity.

Various types of plaster, varying in the time taken to set, the amount of water needed to make a pourable slip, and the final hardness, are made for different applications. These characteristics are controlled by the calcination conditions (temperature and pressure) and by additions to the plaster. For example, hydrated calcium sulfate ($CaSO_4 \cdot 2H_2O$) greatly accelerates the setting time and therefore the use of utensils contaminated with set plaster is to be avoided. *See* GYPSUM; PLASTER.

[M.C.M.]

Plastic deformation of metal

The permanent change in shape of a metal as a result of exceeding the elastic limit. The plasticity of a metal permits it to be molded or pressed without rupture into various forms that are retained after the pressure of molding or pressing has been removed. For a discussion of conditions under which changes in shape are not permanent, *see* ELASTICITY.

The properties of metals that are associated with plastic deformation are ductility (the ability of a metal to be deformed considerably before breaking), creep (the time-dependent deformation of metal under stress), and malleability (the ductility of a metal under the particular conditions of a given metal-forming operation). *See* METAL; METAL, MECHANICAL PROPERTIES OF; METAL FORMING.

Ductility. A substance is brittle if it breaks without deforming; it is ductile if it can deform considerably before breaking. Ductility is important in metals for two reasons. It permits a metal to be put into commercially desirable shapes without breaking, and it permits a metal to absorb shocks and blows in service that could break a stronger but more brittle material. One simple measure of ductility is the reduction in cross-sectional area that a metal sample will show when pulled apart in simple uniaxial tension. There are metals that are as brittle as glass, showing virtually no reduction in cross-sectional area in a tensile test, whereas others will be as ductile as taffy, stretching out in a tensile test until the cross section of the sample has contracted to a mere filament. Ductility is not a fixed property of a given metal but will depend upon such factors as the temperature, the speed with which the metal is broken, the size and shape of the metal, impurities that may be present in the metal, the environment in which the metal finds itself, and the manner in which the metal deforms prior to breaking.

In a tensile test, the metals crystallizing in the face-centered cubic system (for example, copper, aluminum, nickel, lead) are generally ductile at all temperatures and rates of deformation (strain), although even these metals (especially those with large grain size) show some brittleness in some combinations of temperatures and deformation rate, as shown by the valley *A-A* in Fig. 1. Since the metal deforms plastically at temperature below this valley and viscously at temperatures above it, this brittleness is usually associated with the high degree of deformation occurring in the few regions of the internal structure of the metal where viscous flow first makes its appearance. The term equicohesive brittleness is usually applied to this phenomenon. A quantitative measure of ductility is the ratio of the cross-sectional areas of the test piece before (a_0) and after (a_f) the piece failed. Since the range of this ratio is large, the logarithm of the ratio is usually plotted (see Figs. 1, 2, 3, 4) and for theoretical reasons the natural logarithm may be used.

Certain of the close-packed hexagonal metals (notably zinc and cadmium, but not titanium or zirconium) and certain of the body-centered cubic metals (notably iron, chromium, tungsten, and molybdenum, but not vanadium or tantalum) become brittle at low temperatures and at high deformation rates (Fig. 2). This phenomenon is the basic cause for the dramatic failure of steel structures in cold weather under shock (for example, the breaking in half of the ocean freighter *Flying En-*

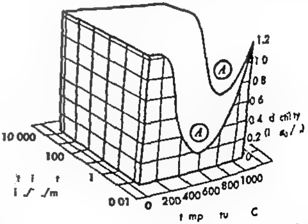
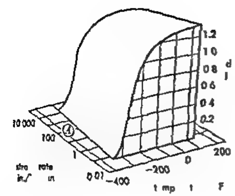


Fig. 1. Ductility of copper in a tensile test (measured by the natural logarithm of the ratio of cross-sectional area of the specimen before (a_0) and after (a_f) the test) as a function of temperature and test speed.



Fg 2 D t lty f al d m ld t el t n l te t f ct f t mp t d t st pe d M tal rtu lly gl -b ttl t l w t mpe t d h gh stra rat (g A) (F m T T h d W M B ld J W D R b rt d St C C k g d Emb ttl m t W l y 1956)

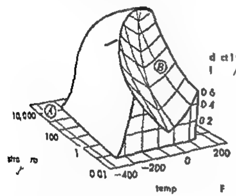
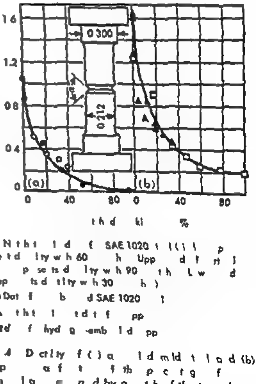


Fig 3 Duct l ty F l d m ld st l ch g d w th hydrog f ct f temp t d t t p d Pres c of hyd g ll d pe d the d t lty f th st l g ll B ttl g A t wh the hyd g l p se t t (F m T T h d W M B ld J W D R b t d St C rr C k g d Emb ttl m t W l y 1956)

t p the N th Atl nt J n ary 1955) D l ed mpu it wh h d ff thro gh h some m b l ty t the h t metal w ll ff t th d t l ty f th h t m tal c ta ge f temp t a d def rm t tes If by a tabl h f t mpe atu the m bilit f th m P it n be h nged so that it l s n m t l y port n t th d f rm t t th movement f th h t m t l t m g i g to m k p th d f rm t on mech i m m y w ll be h m pered d f tl e w ll result Figu e 3 h w f x mpl h w steel nt g hyd g n d play a b ttl nes o c rt t mp at res d d f rm t n a ges (eg B f F g 3) Th d l tio t th l t mp tu e br ttl n wh ch teels posses h the they ta n hyd g not (reg n A f F g 2 nd 3)

N t h n th fa of h le w th m tal per m d t w ll ffect th du til ty in tw ways They will lower the general level of ductility of ll metals and they will hift the cl ff whi h b unds the low temperature brittle range of Fig 2 to h gher temp ratu es and lower strain rate Both f the effect become g eater a the are f cr ss sect on occupied by the notches or holes bec mes larger (F g 4) and b th of these effect (f r a given proporti n of the cro s ection occupied by notch s r holes) will ary in inte sity from metal to metal Th se n iderations are im portant beca se a en teel when tested as a m oth bar in a mple ten io te t may be quite d t le a d yet when fab icated into a machine pa t c ntaining not hes holes may be danger ously b ittle The embrittling ffects of bl w holes from imprope casti g r o ds introduced by im p oper an e li g (for e ample the hydrogen an nealing f xygen bearing copper) tem f om th s s me c s Und ss lved impuritie who hard ne ses a e markedly d fferent from that of the host met l (ther harder or ofter) a e mbrittl ng be ca se th y effecti ely beh ve as holes (discont nu ties) in th matr x In a simil r vein brittle ski s put on m tal i tent ally (c rb ized r n trided ca es put on steel or chromi m and copper pl t s) o un ntentio ally (xygen or n trogen rich su fa e i tit nium a nealed in a r) will em b ittl th b se met l At the l ghtest defo mat on



O N t h t l d f SAE 1020 t l (l l p se t d lty w h 60 h Upp d f rt l (p se ts d lty w h 90 t h L w d rep ts d t l ty w h 30 h)
● Dot f b d SAE 1020 l
▲ t h t l t d t f pp
□ d f hyd g -emb l d pp

Fg 4 D ct l ty f ( ) a l d m ld t l a d (b) pp a f t f th p c t g f ch l a p d by a t h f th typ h w th k t h (p ymb l) f t f th p) g f s- t l p d by a b ttl k (fill d ymb l) (F m W F m d W M B ldw J Th Eff ct f B ttl Sk th D tlity f M t l Am S T st g M t l P e- p t 79 1956)

de cription of the casting method of ceramic form ing *see* CERAMIC TECHNOLOGY

When the powdered hemihydrate is mixed with water to form a paste or slurry the calcining reac tion is reversed and a solid mass of interlocking gypsum crystals with moderate strength is formed Upon setting there is very little if any dimen sional change making the material suitable for ac curate molds and models

The chemical reaction of hydration requires 18 6 lb of water for each 100 lb of pla ter of paris any excess of water over this makes the mixture more fluid and it eventually evaporates leaving a porous tructure In general the greater the poros ity the lower the strength of the set plaster Plaster of paris molds for ceramic casting must have a cer tain minimum porosity in order to absorb water from the slip thus for this application the amount of water added represents a compromise between the conflicting properties of high strength and high porosity

Various types of plaster varying in the time taken to set the amount of water needed to make a pourable slip and the final hardness are made for different applications These characteristics are controlled by the cal ination conditions (tempera ture and pressure) and by additions to the plaster For example hydrated calcium sulfate ($CaSO_4$ $2H$ O) greatly accelerates the setting time and therefore the use of utensils contaminated with et plaster is to be avoided *See* GYPSUM PLASTER

[M C M]

Plastic deformation of metal

The permanent change in shape of a metal as a re sult of exceeding the elastic limit The pla ticity of a metal permits it to be molded or pre sed ithout rupture into various forms that are retained after the pre sure of molding or pressing has been re moved For a di cussion of conditions under which changes in shape are not permanent *see* ELASTIC ITY

The properties of metals that are associated with plastic deformation are ductility (the ability of a metal to be deformed considerably before break ing) creep (the time dependent deformation of metal under stre s) and malleability (the ductility of a metal under the particular conditions of a given metal forming operation) *See* METAL METAL MECHANICAL PROPERTIES OF METAL FORM ING

Ductility A sub tance i brittle if it breaks without deforming it is ductile if it can deform con iderably before breaking Ductility is imp r tant in metal for two rea on It permits a metal to be put into commercially de irable hape with out breaking and it permits a metal t ab orb hocks and l lows in ervice that uld break a stronger but m re brittle material One imple mea ure of ductility is the reduction in cro s ectional area that a metal ample will how when pulled apart in imple uniaxial ten ion There are metals that are as brittle as gla s h wing virtually no reduction in cross ectional area in a ten ile test whereas others will be as ductile as taff stretching out in a tensile test until the cro ec tion of the ample has contracted to a mere fila ment Ductility is not a fixed property of a given metal but will depend upon such factors as the tem perature the speed with which the metal i bro ken the size and shape of the metal impurities that may be pre ent in the metal the environment in which the metal finds it elf and the manner in which the metal deforms prior to breakin

In a tensile test the metals cry tallizing in the face centered cubic system (for example copper aluminum nickel lead) are generally ductile at all temperatures and rates of deformation train al though even these metals (especially tho e with large grain size) show some brittlene s in ome combinations of temperatures and deformation rates as shown by the valley *A A* in Fi 1 Since the metal deforms plastically at temperatures be low this valley and viscously at temperatures above it this brittleness is usually associated with the high degree of deformation occurrin in the fe regions of the internal structure of the metal here viscous flow first makes its appearance The term equicohesive brittleness is usually applied to thi phenomenon A quantitative measure of ductility i the ratio of the cross sectional areas of the te t piece before (a_0) and after (a_f) the piece failed Since the range of this ratio is large the logarithm of the ratio is u ually plotted (ee Fig 1 3 4) and for theoretical reasons the natural logarithm may be u ed

Certain of the close packed hexagonal metals (notably zinc and cadmium but not titanium or zirconium) and certain of the body centered cu bic metals (notably iron chromium tungsten and molybdenum but not vanadium or tantalum) be come brittle at low temperatures and at high de formation rates (Fig 2) This phenomenon is the basic cau e for the dramatic failure of steel truc tures in cold weather under hock (for example the breaking in half of the ocean freighter *Flying En*

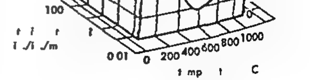
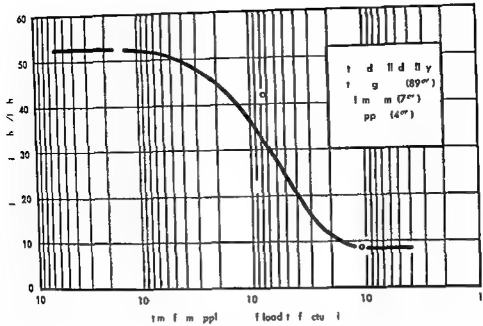


Fig 1 D ct l ty of copp a tens le test (m su ed by th nat l loga thm of th at o f c s-se t or a of t l sp cim bef (a) a d ft ( ) the te t) a a f t o of t mp t t speed



Fg 7 Th d ct l ty f t d ll d -al m -copp t t ll y t g 89% 7 ! m d 4% c pp (h m d l g t t l t t) d p ff th t t speed d p W R h J L H ght d K. E. B gh m wh p rt d th d t t d th t th ll y fl w t p u d th h l t l wly d th t the ll y b k l k gl wh b t p dly o t k b t ld b d bl d t lf f b t lowly (F m W R h J L H ght d K E B gh m Z ll y w th l m m d pp J I M t l 23 261–324 1920)

ll al r l t n betwee eep t d tim t R the g nst t T the b ol t tempe t and Q a o t t qual to the t ati e gy f d ff of th metal i q t n Th t n r te w ll ry w th e h metal d depe d p f t h a t mp nd g ain s z

Th d t l ty of p g m t l f ll ff the d f rm ti r te i peed d p (F g 7) Th be h i t f nd i c s o- l st m t r ls in g l f mple n azy p tty f s nd n l l d in gla s Th t r t t h h th d t l ty dde ly d p m e t h gh al a t mpe atur ni ed a d c th n A h typ f qu t o

$$= Ae^{\,9/}$$

h A Q a d R e on ta t

Malleability I th t t t n th s th b l ty f m t l t be lled h mm d w th t b k g lth gh t f eq tly i i t p et d m b d se the b l ty of m t l t b f med by any m h n al p It s th e y f i l m a e f the d t l ty of met l unde th p r l r d t n f g n f rm g p a t s m t l f med mm l per t t le t d t mp t n well t o m t mpe t met l p od c w ll e n d both th h t d ld m ll b l ty f met l Th term h t h rt ld h rt ef r t m t l l k g h t r ld m ll b l ty

A y f th f m f b ttl d c ed th p g ph d t l ty m y b p bl f m f rm f h t ld h t es M t m t l that mme cially f med fre f m mo t types of b ttlene d th s of h t r ld hortn s t which th y may e io lly suc mb ar used by an unw ted appe a f imp r t e

H t sh t e u lly i cau d by ome e d ph (f eq e tly pr t i f act s of per t) th t turn liqu d t the tempe ture qu t a d wh h by r g between the g n b d te dest y all hes of th ho t metal The lati es f e te s s f the l q d ph se d the h t m t l w ll det m e wheth th l qu d ph w ll r f e ly o w ll b ll up i harmless d pl ts

Le d de pp hot h rt f p ese t i q a tit m re tha 0 02% B s (c pp r zinc lloy) nt l te m e le d th ppe t lf t l st th call d lpha nge c ta ng 0–35% n wh ch the y t l t t r f the b a s th ame as th t f c pp r (f ce te d b cry t l t t CRYST L S RUCTU E) If o gh (35–45%) i p e nt n b ss t pr d the b ta y t l tru tur (body te d c b y t l t t) th s f c te el t h ps b twee b d lead o d lly lte d th t th le d n w b ll p h mle ly nd b n t l t 2–3% l ad r m nd t ll b h t mall ble

H t h t s d by l q d pha es ca be u te ct d by th dd t o f th d el me ts wh h mb n w th th l q d ph e the t f m ld t d t b the rf t o r l t n h p b tw th l q d d th h t met l A mpl th t l e of ppe f l d i cre s h ply xyg added t pp (F g 8) A

the brittle skin cracks and from this point on the base metal behaves as a notched specimen as shown in Fig 4

Creep Creep is the continuing or time dependent deformation that a metal or any substance evidences when put under stress It is unlike plastic deformation which is fixed (unchanging with time) under stress and permanent (remaining after the stress is removed) and unlike elastic deformation which is fixed and transient (being recovered after the stress is removed) Creep or time dependent deformation is the predominant reaction of metals to stress when temperatures are high that is in the upper half of the temperature range from absolute zero to the melting point of the metal and when stresses are low Elastic deformation predominates at low temperatures and low stresses plastic deformation predominates at high stresses As the temperature approaches the melting point of the metal creep tends toward a truly viscous phenomenon since the deformation rate tends to become constant under a constant stress The higher the applied stress s the greater the deformation rate will be according to the formula $= As$ where A and n are constants n being far in excess of unity At lower temperatures creep becomes more complex After an immediate elastic or plastic response to an applied load the metal will deform with time at a rate that slowly falls off The deformation may settle down to what appears to be a steady rate but ultimately even in tests where the stress is held constant will accelerate at an ever faster pace until the metal breaks The terms primary secondary and tertiary creep are used to describe the stages when the creep rate is falling off remaining constant or accelerating respectively The acceleration of creep rate during tertiary creep is usually ascribed to the breakdown of the internal metal structure as a result of the deformation which has been going on This breakdown can usually be seen under the microscope as voids or cracks opening up at grain boundaries or junctures of grain boundaries Inseparable from the creep phenomenon is creep recovery A metal that crept under load will recover some of the deformation it has accumulated when unloaded Part of the recovery will be immediate being purely elastic in nature but part will slowly accrue with time at an ever decreasing rate

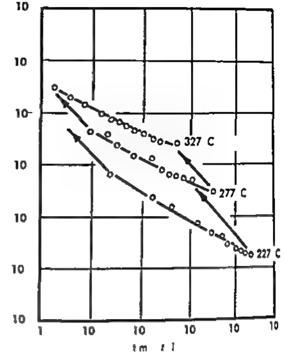


Fig 6 Creep rate of aluminum at three different temperatures plotted against time (stress being constant at 1500 p)

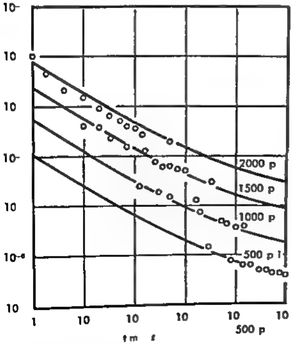


Fig 5 Creep rate of aluminum for four different stresses plotted against time (temperature being constant at 277 C)

Although the creep rate varies with time in the more complex forms of creep (at temperatures not close to the melting point of the metal) it can be predicted with fair success for a given temperature or stress if it is known over a given period of time at another temperature and stress Figure 5 for example shows the logarithm of the creep rate of aluminum plotted against the logarithm of time for four different applied stresses the temperature being held constant It is obvious that increasing the stress merely shifts the curve upward without distorting it in any way Similarly Fig 6 shows the logarithm of the creep rate of aluminum plotted against the logarithm of time for three different temperatures the stress being held constant Increasing the temperature in two 50 steps shifts the curve bodily upward and to the left in equal amount These relations are expressed by the formula

$$= s\, f(te^{Q/RT})$$

Here $\dot{\epsilon}$ is the strain rate in in /in /sec s is the applied stress n is a constant (equal to 3 in the case of aluminum taken for illustration) is the func

hen th stress is remo ed) The study of the e ph nomena ll the manifestat o s i th cience f he logy Fo the influe ce of di locat on n plasti flow in crystals se CRYSTAL DEFECTS *See al o* CREEP OF MATERIALS ELASTICITY HOOKE S LAW PLASTIC DEFORMATION OF METAL RHEOLOGY STRESS AND STRAIN [R F S H]

Plastics fabrication

A ope t on includ ng a ar tv f meth ds for co erti g flu d pastes spen ion powder m les, heets and pe al forms int v n s sol d hape Many e d es depend on m h n c l lt rati ns f n i termed ate pl tic fo m in the me w y that a g eat v ety of obj ct can be m de f om tock metal shape Som pl ti s e almo t re d ly machinable as metals Adhes e bo l g can b ed a ma ner m la to the w ld g of met ls

Th num r us compl cated m mbinatio f fab- r g m thods be s mpl fied g eatly f fin l fi h ng ope at a not co s d ed j st a the p od t n of tanda d teel shapes s mucl le s c mpl ted than the f rm ng f fin hed te l b- jects W th th mpl fi at on pl t fabricat on d to p d i film coat ng m lded a d st object a d t d rd hapes s ch as sheet or ods

Films and coatings *Film a d oati g* an be p od ced by de t al p o es es *Films* ha th ck e es f 0 2 50 mil (0 000 –0 05 n) d are u ally fl ibl The t rm *foil* m y b u d f th n fle bl t n pa t m t ial u d f r p kag g h re h et r h et ng refe t tl i k mate r f th t too g d fo film

Th e ent al teps th f rm tio f film nd film a a e prepa at f the pl t feed stock (mp u d d mi g) f mat n of the film d y g d co d t o i g a d fi sh g De pend g n the et l pr th plast c feed tock m h the f rm of l cquer e am l us- p n o mul p t pl t ma The p l meth ds f film f m ng len d n g i n trus l d p kn fe or roll t g

C l d ng A le d su lly i ts of four l r ll r tat g a hown n F g 1 A pl st m f d betw two rolls wh h q e t out t film th i p es nd e m dd

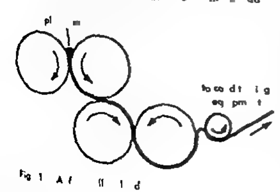


Fig 1 A f ll l d

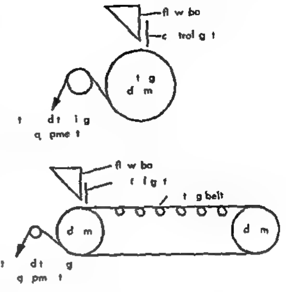


Fig 2 C t ng m h n fo film f m t o

t nal r lls bef re l e ng str pped off as conti u us film Fabric pape may b fed thr ugh the pe g betwe the l t tw lls tl at the film n pr s ed to the surfa to p d ice coating

Th s e pen a ma hine pa t cula lv well ited for the product n of l ge qu ntiti s of yl film and tings thickne of 0 003– 0 010 i nd width up to 92 in It is l o u d n th ubbe nd stry to produce imil film and t ng

Cast g Tl t hn qu of ca ting films n large p l h d whe ls l a long bee used f ph to graph film Ca t n i lso do n poli hed metal belts or b d Both method e h wn d a g ammat lly in F 2 In this method of film fo mat on lution of th pla ti fl ws onto h ghly pol hed mo i g u fa e wh r m he t s applied to ev porate p t f the lvent nd t p d film with eno gh t gth to b elf up- port g at the p t of m al l wheel ca t ng wh el drum *from* 12 t 18 ft n d am ter and p to 6 ft wid a e u ed Th outer *surfa* c re- fully gro d p l sh d nd pl ted w th n k l h m m o lv Th fin hed *surf* ce m t be m m th b au e e n m nute def cts ar e p d d n the film The b lt o b d m hine c s sts f a w de metal b lt st et h d betw tw t u g dr m h u d *m a d* yer W dth p to 100 i a a ailabl d the dr ms a pac d a m h a 300 ft p rt

Th ckn f st film ry fr m 0 0005 to 0 004 n Th wh l pr es i cap bl of p od c t g b tte rf es d is u ed f r ph t graph c film b t the belt method *an* b u d f fa t p o- d cti M y pla t film s h c llulo a t te a d cet te-b tyrat polyeste s a d the vi nyl a e p od i d by t g

Cell pha e l pr *duced* by p o e call d cast ng In th e the film i *formed* by ch m al gulat n Th m thod of f rmat on s the am th t for e rayo x ept th t a w d h d

Impurities commonly rendering some metals hot short and their counteractants

H st metal	Impurit es pro duc ng hot shortness	C unte actant
Iron	Sulfur (0 017)	M ng n
Au t nit t n less steels	Lead (0 005)	O yg n
N k l	Sulfu (0 004)	Magne um m ng nes
	S l on (0 3)	M ng nes
	Lead (0 004)	O ygen
C balt	S lfur (0 010)	M gn s um
Copper	L d (0 0 0)	Oxyg n
	B smuth (0 00)	O ygen

Th numb rs n p nth th t cal l m ts of th mpurity (%) wh h the host metal can tole at f h t lling

brief resume of some common impurities that render metals hot short and some counteractants to these impurities are assembled in the table

If impurities render a metal cold short it is usually because they occur as fine precipitates either at the grain boundaries of the host metal or throughout the entire matrix As noted abo e if the hardness of these particles is sufficiently different from that of the matrix they act effectively as holes and embrittle the metal through a notch effect Fig

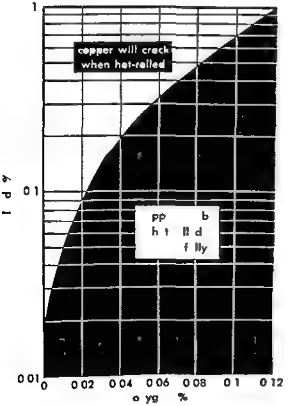
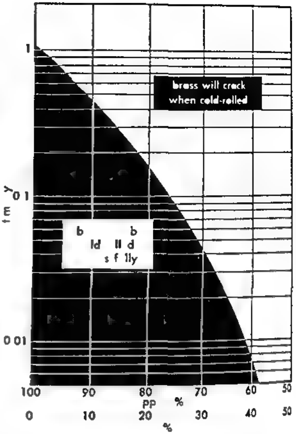


Fig 8 Th chart shows the lead a d o ygen co t nts that copper ca t le te and b h t malleabl The r cher copper is i oxygen th mo e lead it ca cont n a d not be hot sh rt (Fr m W M B ldw Jr Roll g Copper a d Copper Alloys n N f o s Roll ng Pr ct ce Am Inst M ng Met E grs I st M tal D Symp s um S r ol 2 1948)



Fg 9 Th chart g es th m mum amou t of a t mony that brasses f d ffere t z nc co tents c n o ta n and st ll be old m lleable (From W M Baldw Jr Roll g oppe a d copper alloys N f us Roll g P a t ce Am I st M n ng M t E g I st M t ls D Symp s m Se l 2 1948)

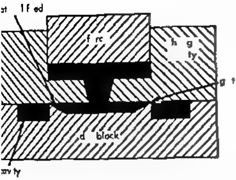
ure 9 for example gives the maximum amount of relatively hard antimony that may be tolerated in relati ely soft brasses of different zinc content if the metal is to be cold rolled The e curve lie just above the solubility curve for antimony in brass Antimony in excess of its solubility limit appears as a hard precipitate in the grain boundaries of the brass and produces cold hortne s See METALLURGY STRESS AND STRAIN [W M B]

Bibliography H C H Carpenter and J M Robertson *Metals* 2 vols 1939 L A Rotherham *C eep of Metals* 1951

Plasticity

The property of a olid body whereby it undergoes a permanent change in hape or ize when subjected to a stress exceeding a particular alue called the yield value Many solid material ole Hooke s law at low stres s but a the tre is increa ed departures from Hooke s law occur and ome plastic flow takes place that i the material does not completely recover its original hape or size when the tre s i relea ed

Plastic beha ior is often accompanied by time dependent effects such as creep (the increa e in train with time at con tant stre) tre relaxation (the decay of tre s with time at con tant strain) and elastic after effect or reco ery (th gradual decrease to a limit



g 6 A t f m ld (F m C C W d g d L H h Pl st M G w-H ll 1947)

ated with t m r ele tri ty t s pply heat t ie m ld Th t es a e filled with p edet ained mo t f p wder pr f m d p e u e ppl ed t b g the tw h l es of th m ld to- ;th Th h t d p e e fl diz the pla tic d th m ld cl sed e y sl wly u t l t i eat d nth l nd

Th e r t typ f pl t es th rm et nd h rm pl t Th f me ts p ure w th h ppl at f he t th l tte eq e c ol g f r c mplet l d fi ti The mo ts be e m ed fr m the m ld n e y h rt le gth f um If a therm pla t ed the m ld m t b ooled bef r p n g C mpr ss o m ldi g n be u ed fo m t pl st m t l b t t m t f q tly pl y d n m ld phe l c ur m l m e nd th th rm et

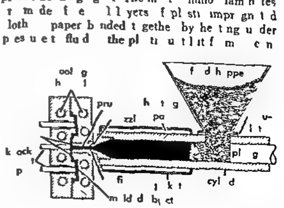
T f m ld g Th p c s i s m l r t c m p m ld g ept th t fl di t ce m pl hed i t de ch mber and the fl id f ed t th m ld c i Th d e m ld typified by F g 6 The t an fe f m th ch g c ty t th pr d ct a ty mpl sh d b th l g f th p e The two m n h l es f the m ld m t th fi t ddit n l m m t f th m pu h the flu d t th h c ty flu d zat t k pl ts de th m ld t th r e t a d m d l at in ert ma b ed Som pl t s lw y l ft n th con ect g p thi m t be m ed d d d d t f th y le r p t d Th method i m lly mpl y d w th th rm ett g pl t ch s the ph l u ea mel m

I j t m ld g In th p oc a h t the mo- pl t jected t c l d m ld th by ob t i g the eed f r lt n t ly he t ng d o l g the m ld G nul pl t m te al pl d i h ppe f m h h t fed p ed te mi d q t ty i h ted h mb l ted f t of h d ul lly pe ted p t S F 7 Aft the m ld l ed th pl g f r es the pla t th gh th h t d l de th th gh zl t th p th f t h lf f the m ld d n th ugh th t th m ld t es P s- es up t 25 000 p ed f j t Th pl t cool p dly a d oo d f je t Th t y l pe t n m y be m d to- matic Fr m 1 to 300 of material may l e in j cted with each hot depe d g on th i e f the m chine Th s the mo t widely u ed m ld ng meth d f r th m pl st It i capable f high prod t n rate p ticularly f multi ity m lds e u ed Nea ly all f the therm pla t a e or an be molded by this pr e s

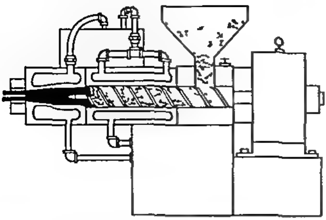
Casting Plast c mater ls c be ca t both l y the use of melts i a ma ner sim l to that u ed for metals d by p lymer zi g liq d m mer in a mold A described pre usly the ame term is used film f rmat M t pla tic re n t uffi ently fl dized below dec mpositi n temperat to fill m lds w th ut the appl cat n of p e r e Howev a few p c al plast comp u d uch s cert i phen lic ethyl cell l e-w x mist d ghly pl tici d cellul e acet te b ityr te m y b melted a d p ed into mold The ma terials a ca t nt l rge pi n hes die nd l l ks ed i f rm ng heet metal

The c ting f rylates poly tyre e p lye ters a d epo des dep ds n polymer zati rather tha c l ng for ha den Liq d m nomer or pa ti lly lymer ed ol t n ut lizi g a mo o- mer as the l t m xed w th cat lyst a d caref lly p ur d i to m ld Cond t n ar ad j ted s that polym zat o t k s pl el ti ly l wly ually t t mpe at e b l w 70 C Sin e the ca t ng liq id ha a el ti ly low vi os ty mold f ces a r produ ed c ur tely If pol shed m ld e u ed a h gh p l h i bt ed o th fi hed art l Pol h d he ts od a d t be of lear p lymethyl m thacryl t a e ob- t n d by s ng pl t gl s t le s t el molds C t g als d f r p tti g o e aps la t n f a tous bj ct Bi l gi al o oth type f p m ns m y be embedded le a ti gs for pr e at o a d d splay Ent el t i al c r u ts may be p tted by pla them i a c ntai er nd p g th st g l q d und th m

Laminating Lam t r pl ti h p con t in g for g mat rial h a fib r cl th paper w d e e s They y all th way f om reinfo d pl st c ta n g l tha 10% fibe t plyw od wh ch u lly ta 8–20% of a pl st c bo d g g t The m t mmo lam n tes r m de f e l l yers f pl sti impr gn t d loth paper b nded t gethe by he t ng u der p es u e t flu d the pl ti u t l it f m c n



Fg 7 A l j t m ld g m h (F m C C W d g d R L H th Pl t M G w-H ll 1947)



Fg 3 A e truder for plast cs (F om C C W d g and R L Hasch Plast cs McGraw H ll 1947)

of liquid instead of liquid filaments is pumped into the coagulating solution *See* FIBER MAN MADE

Extrusion Film is produced by two extrusion methods the slot die or sheet method and the large diameter inflated tul e process An extruder is shown in Fig 3 In the slot die method die hav ing openings of as little as 0 005 in and widths up to 72 in are u ed The plastic material emerges from the die in the form of a hot film which must be cooled rapidly Thin films cannot be made by this method Thicknesses vary from 0 005 to 0 250 in As indicated by the thickness range sheets as well as films can be produced

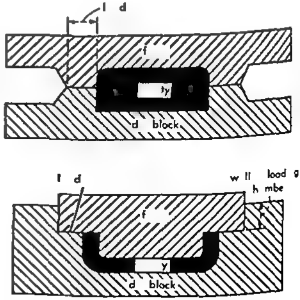
Inflated tube extrusion for film formation in volves extruding a thin walled tube expanding it while hot cooling collapsing and slitting the tube lengthwi e to produce a film with a width equal to the circumference of the inflated tube The proce s is indicated diagrammatically in Fig 4 Inflated diameters from a few inches to 6 ft or more have been used giving film widths up to 20 ft much wider than can be made by any other method Most polyethylene film used in packaging building con struction and agriculture is made by the inflated tube proce s Thicknesses vary from 0 0005 to 0 004 in

Coating processes Various coating methods are u ed to apply plastics to fabrics and paper to pro duce either fini hed goods or intermediates for other fabrication proces es The imple t of the e is dip coating in which a continuou web pa e dov n into a vat containing a pla tic ol ition o er a submerged roller and l ack up out of tl e olution In another method a pla tic in soluti n i poured onto a moving heet and a knife preader di tril utes it evenly over the heet Other meth ds are imilar to printing proces e in which one roll rotates in a olution and tran fer the pla t c ma terial to an intermediate roll which in turn roll a coating onto paper or fal ric

Molding The molding of mall ol ject i the ap plication n rmally thought of when pla tic are mentioned althoi gh the total t nnage i ed for films heet and laminates i actually greater Molding invol e filling a m ld ca ity with a pla tic fluidized l y heat and pre ure whi h i allowed to solidify to produce an object that requires onl fini hing operations With the exception of lami nating and heet forming there are three prin ipal plastic molding proce es which convert po der or granules (or simple preform made by com pre sing powders) into fini hed molded object

Compression moldin In thi proce the t o halves of molds such as tho e hown in Fig 5 are attached to the tv o platens of a hydraulic press one of v hich is moved by the ram The platens are

Fg 4 The nflated tube p ocess (U S I I dust I Chem cals Co)



Fg 5 Tw types of comp s m ld (Fr m C C W d g a d R L H h Pl t c cG w-H ll 1947)

des ed profile Atm sph r c p e s re forces
ft ned l eet g t st the m lded rface Ex
m ly fine d t I may be epr duced The h llow
jects m de by this m thod are me pens ve Spe-
il grades of c llul e acetate v nyl and polysty
heets are m de fo c um f rming Sign
c rat o s b and top g aph cal maps a e
pical prod t *See* POLYMER [C.C.WI]

B bl og phy C. C. Wind ng and R L. Ha cl e
l t 1947

late structural

. fl t plate o sl b whi l s upported alon the
dges, uch a the b tt m r o e of a tank cyl
r h ad b lkhe d r floor panel A tructu al
late b ds when subje ted to forc ppl ed no
al t t surface The b ndi g pr d ce c rvat re
s fl pla e m l t the plat th d h g a
d ffe s f m b d ng f a b am where urva
ur occ s a ngl pl n und symmetric l
a A f r b m b d y c d ti s luded
d gr of re t nt t the edg s fr m m
il upp rt to ompl te fixity against rotat n
The alys of t e a d d fl ct s n a plate
hile b ed on umpt ns s ti lly th am s
tho u d f be m m e mpl at d b e e
l multa eou be d g all pla S mpl fied
app ximate a aly e p ed t tre e nd defle
ti useful in de gn S BEAM

Bases for design Th el t e imp rt n of
th t n g t n ol d dep ds n the th k
n s d h th the beha o s elasti r la
t F r th ck pl te as for h t d ep b am
shearing t e ses must b con idered whereas in
plate f medium th cknes hear stre es can be
neglected and only b nding action is important In
th n plates defle tion relati ely large nd direct
tens on due t u pen i n action appreciable
F r the e t eme e se of a thin membrane re t
ance dep nds almost entirely on d rect *tension*
El st deflection is c u ed primar ly by ben ling
but d ring pla tic bef a ior deflection are in
c ea d a d direct tensio rest is a progressi ely
la ger part of th loads

The flexure theory f r plates ba ed n a ump-
t ons imilar to th ed for beams c n iders the
q il b ium of a differential element of a symmet
rically lo d d plate i cluded between vertical c r
cumfe enti l and meridianal plan referred to
a s of symmetr The nternal stresse and mo-
ments re evalu ted in terms f angular d l near
di f any point f th plate Appl catio
of the g n ral e p e ions to part cular load ng
and supp rt co d tions determ es th maximum
be d g moment Other meth ds i ol e d ff r
t ati n of an xpre i n fo deflection The stre es
S are calc lat d by the fle u e formul $S = MC/I$
whe *M* i bendi g m ment *C* s the d tance fr m
th neut l a is and *I* is the m m t f i e tia

The the ry as umes elast act on negle t g
he a d d re t t ns n A implified appr imate
app ach val ate th total be ding moment on a
c t cal ct n by tat s n i the a rage bending
st e by th flexu f rmul Max mum tre es
a e th n f nd by pplyi g cor e ti n f ct d
t rm ned by mpa i on w th m r exact an ly
o e p im ntal r lt The e an ly s a sume
m ll defl cti ns and be d g s th p ma y ac
t

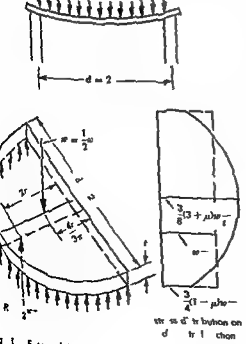


Fig 1 E tern l f th h lf pl t d d
in nalys f f mly lo d d l pl t

Circular plate A mply dge supp rted irc lar
plate n b a alyzed app imately by con der
ng the b ndi g of h lf of th plate bo t a d m
tral is f ymm t y

Un fo m l ad W th n f rm load th nalysis
determ n s the a e e bend ng tre s n a d amet
i l ecti o (Fig 1) Th es lta t t t l be ding
m ment the d met al e t n d e t the load
nd e ct n /3 The ect n modulus r /3
nd th ver g l e d ng t s t th u face
$S = \mu\ ^2/t$ wh re th ymb ls defined a in
Fi 1

A rdi g to the r l theo y of flexure of
pl t the st e e ch ma mum lu t the
c t r eq l t $(3/8)(3+\mu)w\ /t$ wh ch f r
teel with a P i n r t o $\mu = 0.30$ is 24
gre t than th age Redi t ib tion after l cal
y ld ng at the ent r te d to if m ty f tress
d t t h hown th t the a e ag st e s can be
take the ig fi t st e s

Elastic d fl t on at the c nt m ll x ept
f r y th pl t F r c ul plat imply
dge- pp t d d fl cti n y is

$$y = \frac{3}{16}(1-\mu)(5+\mu)\frac{}{Et}$$

F $\mu = 0.30$ $y = (11.06)$ ...

tinuous phase surrounding the fibers. Mats of fibers may be used in place of cloth or paper.

Both molded and standard shapes may be made by lamination. If a molded shape such as a boat is to be made, a mat of fibers (usually glass) is first laid inside a female mold having the shape of the hull. The fibers are impregnated by pouring a liquid resin over them. A rubber or plastic blanket is then placed over the fibers, the edges are sealed, and the air in the fibers between the blanket and the mold is driven out by a vacuum pump. Since the rubber blanket is flexible, atmospheric pressure pushes the laminate perpendicularly against the mold. The whole mold is then heated to cure the plastic. The heat and pressure forms a strong laminate in the shape of the mold.

A large number of variations of this process are in use. Cloth or wood veneers may be used in place of mats. Matched and metal molds may be used to apply pressure and heat. Chairs and boxes are made by employing glass fiber mats in matched molds. Rubber bags or diaphragms may be inflated with steam so that they press against the laminate. Glass cloth may be laid over a male mold, impregnated with a plastic solution, and allowed to dry; the process may be repeated until a laminate of the desired thickness is obtained. Different resins which cure to a plastic are used in various modifications depending on temperature available for curing and the kind of laminating material. Polyesters dissolved in a monomer such as styrene require the addition of a catalyst just before use and can be cured at room temperature. Epoxy resins usually require heating and give an excellent product. Phenolics and melamines require heating.

In the production of standard shapes such as large sheets, cloth or paper is first continuously impregnated with a resin solution by the dip coating process previously described. The impregnated material is then cut into sheets (usually 4 × 8 ft) and as many as 10–100 of them piled together and placed in a large press where heat and pressure are applied. Paper laminates may have a printed outer layer for decoration. Such sheets are commonly used for table and desk tops. Cloth and fiber laminates are converted into a variety of industrial products by stamping and machining. Tubes and rods are produced by rolling several layers on a mandrel, removing the mandrel, and curing in split molds. Phenolic, urea, melamine, and polyester plastics are used as impregnating resins; curing is done at 200–350 F.

Laminates have much higher strength than plastic products which do not contain reinforcing agents. They can be used for building construction, furniture, boats, and other products requiring high strength.

Extrusion An extruder is illustrated in Fig. 3. The die at the point where the plastic emerges may have a variety of shapes in addition to the long slot described under films. Tubes, rods, angles, and many other shapes may be made using special dies. Plastic pipe, tubing, hose, insulated wire, and

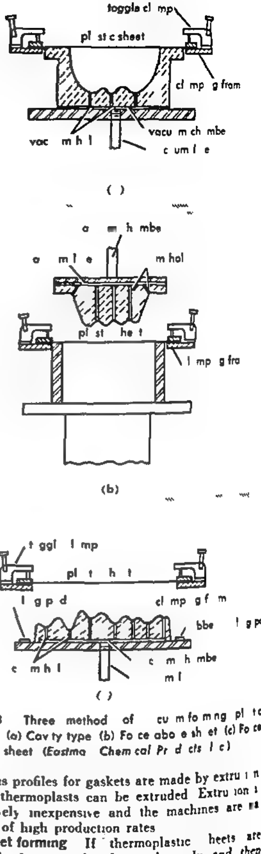
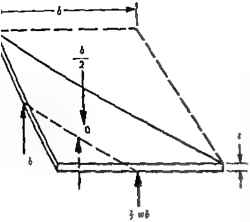


Fig. 8 Three methods of vacuum forming plastic sheets. (a) Cavity type. (b) Force above sheet. (c) Force below sheet. (Eastman Chemical Products, Inc.)

various profiles for gaskets are made by extrusion. Most thermoplasts can be extruded. Extrusion is relatively inexpensive and the machines are capable of high production rates.

Sheet forming If thermoplastic sheets are heated, they can be distorted easily and then cooled to retain their shape. In the simplest applications they may be bent over a mandrel or sealed at the edges and blown against a shaped surface with compressed air. Three methods of vacuum forming are illustrated in Fig. 8. In all variations of vacuum forming, either a vacuum which exhausts the air behind the sheet through holes in the cavity or a force is used to bring a heated softened sheet into contact with a surface having



ig 4 F t g l h lf pl t rv t o f mly l d d qu e pl t

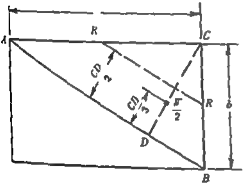


Fig 5 R ct g l gl t mply pp rt d d f rmly l d d

Square plate Whe mply pp t d t ll edges w th ■ f rml d tr b ted l ad q re pl t b a l ed f ll w The t c l e t n t ke l g th d g l f the qua e bo t wh h m m m t c u Th be d ng m t n a d ■ al t ı f d by side gth f r ■ the t ı g l r half pl t (F g 4) Th lt t f th appl d l d d t n d th l c t o d t m the be dı g m m t n th d g l t n wh h $M = b/12\sqrt{2}$ Th ı rage tr ı th d g l ect n wb t h h the m fo a l plat th d m t q l t th d f th sq W th fi ed edg pp rt th g t th d g l t tak n ı wb 5t

R t gul pl t A mply pp t d t g l pl t th u f mly d t b t d l ad aga h th rı l ect n l g th dı go l B a e f mm t th r lta t edg tı a e t th l f lh d (F g 5) O th l lf re t ngl l pply g u d t t q l b m th a g t th d g l t

$$S_a = \frac{1}{+b} \frac{b^2}{t}$$

F b th p r d t th t f squ ■ pl te Fo a rectangle th stre s ıs always great ■ ın the d rectı n of the shorte span For a/b ■ y la ge the a erag stre s across a mıds ■ t on parallel t the sıdes appro che that of a sım ply s ıppo ted pl te w th p n = b and $S = 3wb/4t$

Concentrated load at center A ımply upported q a e pl te with a c ce t ted l ad P appl ed to a central a a of d mete d_0 has n average be d ı g tress ■ the d ag n l ectıon $S = 3P/4t$ Howe ■ the max m m st ■ s at the center found from the th ory of flexu ■ f plates bv H M W es terg ard ıs ■ ns de ably larg r $S = 2\ 64\ P/t$ for $\mu = \frac{1}{3}$ Th hıghe st ■ s re lo alized and plas t c yı ld g whı h c u ed trıl utıon does ot gre tly affect the pl te a whole For l rıttle ma te als o cyl c load ng ın l ng fat g e the hıgh l c l ed t e ■ımp rtant

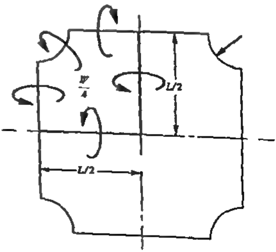
Co tı o pl tes In me a the plat ex te d beyo d ıt s ppo ts Important e ampl ar fl t fl or slab s pp rted by eq ally spaced col umn and tayed flat te l pl ■ u d a b ıl h ad

F r pl tes upp rted by rod r t ys attached s a t dı de the plate to eq al q ar panel the m x m m be d ng tre a co dıng to U wı ıs

$$S = \frac{2}{9} w \frac{}{t}$$

wh z ıs th k ■ d tan e between pp rts (de f th pa el) a d w un f rmly d t b t d l ad p u ıt a e All u ıts ı cl

A fl l b m y be pp ted by cı c lar c l um s L d t e ap rt and d v dıng th continuo s pl te t sq a e p n l (F g 6) The aly n l e mom t at fi e edg s of qu rt panel Th d tr b tı n f mome t al ng the ext r ed es nkn wn nd the p blem t t cally ın d term te F m th theo y of fl e W t ■ rd f nd p e s n fo the mome t p u t wıdth t a o locat ns ı the panel ın terms of th age m me t p r t wıdth al ng o e en



Fg 6 C t pl t

Edges clamped Circular plates fixed in direction at the edges and uniformly loaded are analogous to fixed end beams where negative moments at the end reduce stress and deflection at the center The moment is greatest at the edge The maximum radial bending stress at the edges is $3wr^2/4t^2$ For thin plates the elastic deflection at the center is

$$y = \frac{3}{16}(1 - \mu^2)\frac{wr^4}{Et^3}$$

For $\mu = 0.30$ this is only 24.5% of the deflection of a simply supported plate

For thicker plates with $t/r > 0.1$ the above value is multiplied by a factor $C = 1 + 5.72(t/r)$ Complete edge fixity is an ideal condition Because edge rotation is small for simply supported plates only a small relaxation of clamping or local yielding will eliminate most of the fixedness and behavior approaches that of a simply supported plate

Central load If the central load is distributed over a circular area of radius r_0 the external forces on a semicircular segment of a simply supported circular plate are the reactions at the rim and the load on the area of application (Fig 2) The bending moment M on the diametral section is

$$M = \frac{Pr}{\pi}\left(1 - \frac{2r_0}{3r}\right)$$

and the average stress is $S_{avg} = 3P/\pi t^2$ As the load application area decreases r_0 approaches zero and the average stress approaches $3P/\pi t^2$

The coefficient to be applied to the average stress to obtain the theoretical maximum stress ($\mu = 1/3$) approaches 1.25 for large values of r_0/r and is nearly 2.20 for $r_0/r = 1/30$

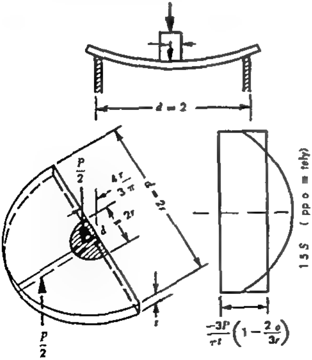


Fig 2 Simply supported circular plate with load concentrated near center

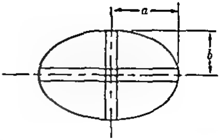


Fig 3 Elliptical plate

The theoretical center deflection is

$$y = \frac{3(1-\mu)(3+\mu)}{4\pi}\frac{Pr^2}{Et^3}$$

With the edges clamped the theoretical maximum stress at the center for $r > 1.7r_0$ is

$$S = \frac{3(1+\mu)P}{2\pi t^2}\left(\ln\frac{r}{r_0} + \frac{r_0^2}{4r^2}\right)$$

Yielding at the fixed edges by ductile materials relieves the local stress and the stresses after redistribution approach those of the simply supported plate

When r_0/r is small the center deflection is

$$y = \frac{3(1-\mu^2)Pr^2}{4\pi Et^3}$$

This deflection increases with yielding at support

Center support A circular plate supported at its center with uniform load has a maximum theoretical stress at the center of

$$S_m = \frac{3wr^2}{2t^2}\left[(1+\mu)\ln\frac{r}{r_0} + \frac{1}{4}(1-\mu)\left(1 - \frac{r_0^2}{r^2}\right)\right]$$

For r_0/r small the term r_0^2/r^2 is negligible Under this condition the center deflection is

$$y_m = \frac{3}{16}(1-\mu)(7+3\mu)\frac{wr^4}{Et^3}$$

When $\mu = 1/3$ this reduces to $y_m = wr^4/Et^3$ which is three fifths of the deflection for the same central load on an edge supported plate

Elliptical plate In an elliptical plate simply supported at its edges and with uniform load the maximum bending stress and curvature occur in the direction of the minor axis (Fig 3) If the ellipse is elongated with a very much greater than b the plate action approaches that of a simply supported beam with a span of $2b$ A central strip of unit width along the minor axis receives a maximum moment of $wb^2/2$ and the maximum stress in the plate is $3wb^2/t^2$ If a equals b the plate is circular and the maximum average stress is wb^2/t^2 For intermediate dimensions the coefficient of wb^2/t^2 varies between 1 and 3 An approximate expression for maximum stress in the direction of the minor axis is

$$S_m = \frac{3a - 2b}{a}\frac{wb^2}{t^2}$$

d m m m a d r then m plus om nonplat m gro p met l The pl cer dep sits a e the res lt f er f ltraba i rocks a d a e f und n Al ska Colomb a a d the S iet U i n In Can the pl t num m t l e r n the i kel coppe ulfide e and the production is d p nd nt en tir ly up n the dema d f r n ckel The plat num co tent of thes res mewh t but i of th o d r f I part pe milli n pr ct c lly all of h h r overed Th pl t n fe o s o e of South Afr a contai m n r am u t f copp r and n k l b t thes o es are min d p ma ly f r ther platin m c nt t The South African gold m n al y ld mall amo t of o m rid um co tain g abo t 35% m m and 30% r dium a d ir do mi wh h c t s b ut 40% ir dium Small am u t of the pl ti um m tals pall d um in pa ti l re re o e d du i th ele t olytic efin ing f pp The major u ces of plati um met al Canada S th Afri a, and the Sov et U n.

Th princ p l pl t n m m n ral a e plat num senide (sp yl te) pl t m sulfid (c pp r t) p t um p ll d um n kel sulfide (brag g t) at v plati um o m ridium d i id m ne

Uses Th plat m gr up met ls ha e w de in dustr al u e b c u of their talyt c activ ty h m cal inert ess nd high melt ng p ints As a a ly t, platin m i used n hyd o atı n dehy dr genat i me zat n cycl z t on d hyd a u d h l g t n nd idat o ct ons Finel d v ded plati um n aluminum ide s ed pgr d th o ta ti g f g l by at lyt i lly c l r t g a e mpl x rne f dehydro- g n t hyd g n t s mer z ti n and y l zati r ct s Plati m h d um ll y g z re u ed in th atalyt xidat f ammo to f rm it c ac d o x d of n tr g n Wh th proces is rried o t in th presen e of methan hyd ocy n a d form d Pl ti um a c taly t in the ld o t et p oce s f r mak g s lfu c ac d the n e n f rbon m n xide i ca b n d d by c mbi ati w th oxygen th ecombi f hyd g n d yg n i fo m wat n the ed ti n f ntr g ups a d th r mo al f t g (II) ox d f m g tream by t n th hyd g n t f rm n t gen a d wat Plat n m a d pl t um all y r used ma y pec l ppl c t n lud g l bl nodes jewelry p e t u ed in y thet c fib ext qu p- ment l m lt tir g and trud g molt gl th rmoc uple e ta n th m met lectri l cont t d nt l nd med l de e corro o es t nt labo at ry t l el tri furn w d ng t lyt c gas gn t rs p es u e rupt e d k nd g ids f pec l pu p u m t bes.

Alloys P e plat n m i soft nd d t l Mod t h d es s bt ed w th the dd t n of 0.5% id m o 3.5% rhod m S h alloy re used i th m n f t r f labo t ry t n l F jew lry 5–10% di m o a 5% r the m all y used The 10% hod um lloy i ed n the mo- c uple ammo i x d ti n catalysts p nnerets fu n c win l ngs nd f r molten glas ha dli g q ipme t A 13% rhodium alloy i lso used f r the moc upl s A 4% t ngsten alloy is u ed as heavy duty el ct ode in aircraft and indu trial p rk plugs

Chemical and physical properties The at mic n mber f platin m i 78 atomic we ght 195 09 den ity 21 45 g/cm melting p int 1769 C b il ng po nt 4530 C, and ele tr cal re i tivity 10 6 mi c oh n per cent m t t 0 C. Radi a tive i tope of the following ma numb s a e kn wn 187 188 189 190 191 193 197 nd 199 The table is t p f pl tinum ha e the ma s number 192 194 195 196 a d 198 Th nat ral abundan e of the e a e 0 8 30 2 35 3 26 6 and 7 2% r pec t ely Plat num not tta ked at ro m t mpera tu by any s ngle ac d but it i r ad ly di lved by hot aqu regi Alth ugh it s re stant to hy drogen chl ride t ele ated temperat r s it doe r a t with chlo ne at ab ut 500 C. It i e i tant to me cury fu d sulfate chlorides a d ca b n tes Plat num exh bits valen e tat s of 1+ 2+ 3+ 4+ and 6+ The 2+ and 4+ vale c s ar the m t common Plat num an be m d into po gy form by th rm lly d omp i g amm ni m chl platı te by d cing it from a a queou sol t In this f rm it exh bit a h h al so pt e pow r fo ga es pecially xyg hyd og n and a b n m no id The l gh talyti acti ty of pl t um is el t d d r ctly t th s p p ty Hy drog n d flu s thr ugh h ated pl t um Pl t n m ha st g tenden y t form o d to om p u d

Metallurgical extraction There i n n tine method for the ext a t n of pl t um The method u ed s depe dent upon the tart g m t rial which may be s ap r ed ataly t sl m s re lt i g f m n k l r c pp n e s g er d plat n m r th ery efract y m r d m o i dos m ne The pl t n m an b ext a ted w th aqu g a n s m se In ther it m b nec s ry to f e the w th a u t ble fl x a d t coll t th pl ti m g oup met ls a c r te u h a pp r l ad When a hyd hlo ic acid olut on f plati um i xid ed a d then made ba i m st f the impurit e p p t te hy d d and the pl ti um em l t 4 im la p ifi at n a b bt n d by rti g th plat n m t th h a t to mpl wh h d e o p p tate n b fut on Wh n a h d o hlo ac d l t n f platin m(IV) i t e t d with mm m hl ride th pl t n m i al st mplet ly p ecip t t d s mm m hloroplat nat The hl pl ti at i re d ly n t d t th m tal by therm l d comp t o Plat num can l h edu ed t th met l f m q e us olu t of t alts by nc magne m or l m n m Th pl t n m d l t aq e solut n a al o be p p tated th ulfide a d the eb t ted Th fi ng of a p c fi m t l n t f a e mh t n f th meth d In ad d ti n t epa at ng th p ou met l f m ll

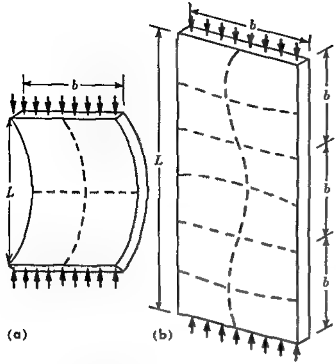


Fig 7 Buckling of plates due to distributed loads on ends (a) Edges free (b) Edges simply supported

tire side of the panel The expression take the form

$$M/\text{unit width} = K(w/8)(L - 2d_0/3)^2$$

where d_0 is diameter of the column and K has different values according to the location

Buckling of flat plates Thin plates subjected to compression loads in the plane of the plate become unstable at a critical elastic stress and suddenly deflect laterally or develop local wrinkling This susceptibility to buckling depends upon the material constants (E and μ) the ratio of thickness to width or length of the plate and the edge restraint *See* COLUMN

A wide thin plate with load uniformly distributed *along opposite ends free to rotate buckles in primary* bending about the longitudinal axis as a long column (Fig 7) The critical stress initiating buckling is

$$S = \frac{\pi^2 E t^2}{12(1-\mu^2)L^2}$$

In the inelastic range E is replaced by the tangent modulus E

A square plate loaded along opposite ends with edges simply supported so as to be free to rotate but maintained straight buckles with both lateral and longitudinal curvature The elastic buckling stress for a square panel with $b = L$ is

$$S = \frac{\pi^2 E}{3(1-\mu^2)}\left(\frac{t}{b}\right)^2 L$$

This is four times as great as for an edge-free square panel For long panel under end compression with all edges simply supported the critical buckling stress depends on the L/b ratio and such panels will buckle into a series of equivalent square panels when L/b is a whole number (Fig 7b) The general equation for critical elastic buckling stress is $S = KE(t/b)$ where K is a constant depending on edge restraint obtained by the theory of elastic stability For long panels with simply supported edges K may be taken as 3 60

For inelastic buckling an effective modulus replaces E in the elastic formulae such as $\sqrt{EE}$ where E is the tangent modulus [W.J.KR.]

Bibliography A Morley *Strength of Materials*, 11th ed 1954 F B Seeley and J O Smith *Advanced Mechanics of Materials* 2d ed 1957 F R Shanley *Strength of Materials* 1957

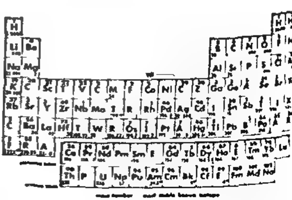
Plateau

Any elevated area of relatively smooth land Usually the term is used more specifically to denote an upland of subdued relief that on at least one side drops off abruptly to adjacent lower land In most instances the upland is cut by deep but widely separated valleys or canyons Small plateaus that stand above their surroundings on all sides are often called tables tablelands or mesas The abrupt edge of a plateau is an escarpment or especially in the western United States a rim In the study of landform development the word plateau is commonly used to refer to any elevated area especially one underlain by nearly horizontal rock strata that once had a smooth surface at high level even though that surface may since have been largely destroyed by valley cutting An example is the now hilly Appalachian Plateau of western Pennsylvania, West Virginia and eastern Kentucky *See* ESCARPMENT

Among the extensive plateau lands of the world are the Colorado and Columbia Plateaus of the western United States the Plateau of Southeastern Brazil the Patagonian Plateau of southern South America the Central Siberian Plateau and the Deccan Plateau of peninsular India [E.H.H.]

Platinum

Chemical element number 78 platinum Pt is a white noble ductile metallic element



Natural occurrence Native platinum found in placers comprises a mixture of the six platinum group metals platinum pall... iridium rh...

l ted hermaphr d t c rep d ct n y t m and sol d me e hym hich fill the i te of th ody Thr l es n t the phyl m (1) th bellar m ly f e li i n preda eous worms) th T ematod r fi ke h l c to- or e l p tes d (3) the Ce toda r tap worm aprozo c e dopar tes the n ter n of v te ates h e l rvae e fou d i the ti es of in ert b tes n teb tes

Morphology Flatw m ti es d o g s deri ed f om three n m l yer Mo t flatw rm n dhes or tt hm nt de ices In t bell , the a gl d l r m c l in fl ke a d estode th a e ck s a d t l ri d ho ks r p es M la ll ue c s i me chym l l rs a d permits pid h ng in body f rm me re pt ell (tang ept d hemo ec pt) a d e n g s (te t cl st t ocy t f b la c d c ll for photor pti n) oc o th h d d b d M ny f the ar e- d ed b ent i n sit c f rms Prim ti e fl t rm p se c le te te-l k n rv t he s h gh f m h e a b a h ad eg s ll a t m in l g t d l erve rd wh h mbl a l dde b u e f th r omm u es A d g t e sy t m pres t n t rbell n and t mat d b t l ck g i est des A m th n g al f g t t ated ith l y o t ally It i fte p ded w th

pirati g ucker o pharynx by which mall or g ms juice f l ger o e or ho t t sue are inge ted The gut i clike r branched and l ned with a ngle l yer of ells often packed with g an ul s D g ti s i t o tra llular The pro- t ephr d al e et ry syst m is f unifo m o str t n n the phyl m It c n s t of ram fyi g bl nd tube capp d with large cell called flame ll e h be ing a t ft of lia which pr jects in the l me The tube cour e thr gh the m s hyme a d d charg at the face by mean of o r mo e pe n Th funct n f thi sy tem n t well under to d The rep d cti e system rea he m ph log c l omplexity beyo d th t f u d i th phyla In ch rep od cti e u t wh ch s the t re organi m i T bellari a d T em t d a d i the pr glott d in the E ce t da o to e e al testes a d aries ccur s well as io s ce ry ep d cti organ

Reproduction The pl tyhelm nthes epr du n b th e ally a d exually In xu l prod t o f til at n s nte nal follow ng copul t o n hyp derm c n m al n Cr ss r elf fe t li zat n m y oc Ex ept n coel a d polyclad fl t w ms the gg are tole thal that s th n i e ted w th yolk cells nd th egg m s is n cl ed in a cap le In turbell ri n n ps le a often d p ited n o i whi h th ju en le d elop Egg of trem todes and est d m ge f m the h sts and e eith e te o h t h i w t a f ee sw mm g larva Th y the ther c t ly p etr t r a e p s ly gested by i t med t ho t

A e al r p d ct o i f f equent o cu re i the phyl m Ma y tu b lla ia repr d ce by f gme t t o bi ry fi s n in me chai of d d ls a temp r ly pr du d T m tod s p d e a e ally (poly mbry ny) i th ir l r l st g a d ome tapeworm ch a *Ech u d M lt ep* F rm to f p ogl tt d n s x l p e s r lt ng f m act ty f a n l fe at g n n ck g on

Economic and biological importance Turbel l a r widesp ad fr sh wat r d the l tt r l z n s f the e wh l n e gr g f tr clad n l d m t h bit t T rbell r a ha b e d t tudy ge t n i l d g the ff cts f hem l a d d t n p the pr e s Th y h l b en sed n a l gr d e t e earch Ad lt t m t d occur on r n p act lly ll t a d e t e of th ert b t n wh h th y f ed Th resp ible f tr bl m d e e m n d imal Larval fl ke f q e t n m ll k ma l ga tr pod d cas lly u in p l cyp d Ve t t u h as i ts d fi h ften te p l ted betwe n m llu k a d rteb t Ad lt t pew rm l g n th e te n the b l y d t compet w th the ho t fo food d a ry f d f ct u h t min Lar l t p worm re d h fly in arth p d b t larv e of e g up th C lophyll de dev lop n m m m l wh h m y be e rely mp ed r e n k lled by the fect I est g t ons util zi g

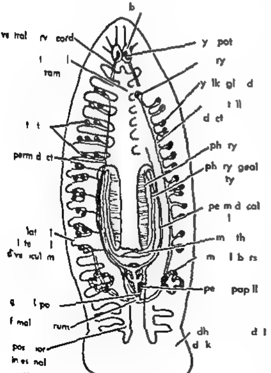


Fig 1 Bd ll dd (T l d d) t mm sol h k g b l m l C mpl d g t d mole sy m h wn l ft f m l sy t m ght

other impurities it is necessary to separate them from each other The refining of precious metals requires a great deal of flexibility on the part of the refiner It is not unusual for a portion of the material to be recycled in the refinery because of the lack of suitable reactions for quantitative separations

Principal compounds Platinum dioxide PtO_2 is a dark brown insoluble compound It is commonly known as Adams catalyst It may be prepared by fusing chloroplatinic acid with sodium nitrate at 500 C Solution of the melt in water separates the salts from the insoluble platinum dioxide Platinum(II) chloride $PtCl_2$ is an olive green water insoluble solid It is made by heating platinum in chlorine at 500 C or by the thermal decomposition of chloroplatinic acid Platinum(II) chloride dissolves in hydrochloric acid to form chloroplatinous acid H_2PtCl_4 which cannot be isolated but which forms soluble salts such as potassium platinum(II) chloride K_2PtCl_4 Chloroplatinic acid H_2PtCl_6 is the most important platinum compound It is made by dissolving platinum in aqua regia destroying the nitric acid by evaporation from a hydrochloric acid solution and then evaporating the solution The chloroplatinic acid is isolated as a hydrate $H_2PtCl_6 \cdot 6H_2O$ The red brown crystals are very soluble in water Ammonium chloroplatinate $(NH_4)_2PtCl_6$ is a lemon yellow crystalline relatively insoluble solid made by adding ammonium chloride to a solution of chloroplatinic acid Compounds such as dichlorodiammino platinum $Pt(NH_3)_2Cl_2$ exhibit cis trans isomerism because of their planar configuration

Analytical techniques If platinum is to be determined in an ore type residue it is collected in lead or silver while fusing the material with a suitable flux Recent data indicates that iron nickel or copper may be superior collection media The metallic residue is dissolved in aqua regia and the nitric acid is destroyed by evaporation from hydrochloric acid The platinum is determined by *reading the optical density of its stannous chloride* complex If it is necessary to remove impurities from the platinum this may be accomplished by passing a solution of the anionic hexachloroplatinum complex through a cation exchanger The impurities are generally cationic and are therefore removed by the resin Hydrolysis or nitrition may also be used Potassium iodide or thiosemicarbazide may be used for the colorimetric determination of platinum Thiophenol has been used for its gravimetric determination *See* HYDROGENATION IRIDIUM OSMIUM PALLADIUM RHODIUM RUTHENIUM [E A HA]

Platyasterida

A Paleozoic order of Asteroidea comprising a single family and characterized by adambulacral and ambulacral ossicles in almost the same horizontal plane The oral surface is therefore flat and the ambulacral groove poorly defined *See* ASTEROIDEA ECHINODERMATA FOSSILS [H B F]

Platycopa

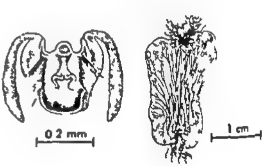
A suborder of the ostracods of the class Crustacea This suborder contains the single family Cytherellidae A heart and eyes are lacking The exopodite and the endopodite of the second antennae are well developed having broad flattened podomeres or appendage segments that distinguish members of this suborder from all other ostracods Both pairs of antennae are capable of being extended anteriorly but are not used for locomotion There are three pairs of postoral appendages none of them leglike In the female the last pair of postoral appendages are rudimentary

Some species have been found only in the profundal sediments of the Atlantic Ocean and the Mediterranean Sea other species inhabit the Caribbean Sea the Arabian Sea and the Gulf of Mexico The genus *Cytherella* created by J Bosquet in 1852 includes present day forms but was established to accommodate fossil forms taken from the Tertiary deposits of France and Belgium *See* OSTRACODA [E F]

Bibliography W L Tressler Marine Ostracoda from the Gulf of Mexico *U S Fish Wildlife Serv Fishery Bull* 55 429–437 1954

Platyctenea

An order of the ctenophores whose members are sedentary or parasitic They often lack ribs in the adult stage They are flattened due to the shortening



Coeloplana bocki

ing of the main axis and by the extension of the pharynx into a creeping sole These organisms are beautifully colored The primary tentacles are well developed and the canals branch profusely to form a network Some are viviparous with the cydippid embryo developing in brood chambers formed by the expansion of the canal *Ctenoplana Coeloplana Tjalfiella Lyrocteis* and *Gastrodes* are representative genera *See* CTENOPHORA TENTACULATA [T K]

Platyhelminthes

A phylum of the invertebrates commonly called the flatworms They are bilaterally symmetrical nonsegmented dorsoventrally flattened worms characterized by lack of coelom anus circulatory and respiratory systems and exo- or endoskeleton They possess a protonephridial excretory system a com

hosts r h ch s x hooked embryos the onco ph res, tra f rm into larval f m uch a p o- ce co ds, pl rocer oid y tic re d ysticerci and the pec l ed type Fi al hosts become fested by i e t ng th larvae One sp cies *Hym olepis n* m y ha a direct life cycl S ACOELOMATA ANIMAL KINGDOM [C C C]

Playa

Th l w e t lly fl t p rt f a ba in or other n d a ed re i id eg At t me of i y r in the playa may be t mp ra ly e ve ed th hallow heet f wat and is tl en a playa k

F pr cip l type f play h ve be n ecog ized by R h d O St The d y playa de el ps h r th w t r table i below cap llary h of f t face is h d fl t a d m oth c m posed f l lt nd clay The m i t play or alina or wh r th water table s with cap llary r ch f u f e th type may be furth r sib- d id d into (1) salt e e st d wh r the wate

Light f d l d p t t th l w t p rt f the ba b l fill g D ath V ll y C lf ia

table i at the urfa e e it that alt w te ev po at g n the f ee l a es lt u t nd (2) l y e r st d wh e the wat table th l m t f c pill ry d lt br ght t th rf e i mi ed w th lt d l y f mi g p fly u f (lf i g g d) Th ry t l hody pl y t lly a m e b dy of rys- tall lt t r y clo e to tl s f e S E AP ORITE (ALI E) The mp nd pl y r lt f m w t r t bl t diffe t le l d ff e t p rt th e sh l t h r t r t f d y pl y P rt nd m i pl ya n othe Th l m p pl f rmed n ba re e g dr n g f m l m t n t rr nd b flon t g f h d t ti S D SERT ER ION F ATURES

[T C]

P bl g phy T Clem t t l *A St dy f D t S l C d t* US A my T h R pt EP 53 19 7

Plecoptera

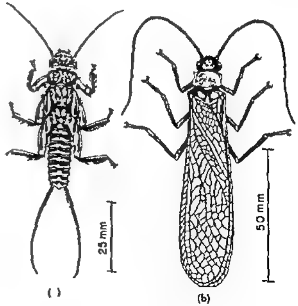
d f ect wn a th t fl Th m g th m t p m ti f in ect F ept f es d t h l g ll th l t ly l ght

differences between aquatic immature stoneflies and aerial mature ones Striki g differences between imm tu e stages are characteristic of pecialized se ts su h as butterflies In stonefl e the oft flattened b dy st ong walking legs p ired claw on each foot biti g mouthparts usty blacks dull yell w and browns are characteristic of both pha e of life

Sto efl es li in clean wift streams through the r immat re nymphal l fe whi h extends from 1 to 3 ye s A compl te l fe hist y of o specie has bee observed n which the nymphs went th ough 22 in tars the form a sumed by an in ect d ri g d el pmental tag The aquat c life of to fl es end when the mature nymphs cl mb nt rock or plant and hed their kins Adults a e p or fl e and are ofte found creep g about on t eam banks and hrubbery The ad lt lif rel ti ely hort Mating occ rs n ar the ground ne er in fl ght Stonefl es that inhabit l rge treams d pos t thei egg directly into swirling water clut hes of pe haps 1400 while tho e f small stre m plac the eggs at the wat r edge

F lamentous t acheal gills are characte i tic f th nymphs cept those th t live n h ghly aerated wate nd b e the th gh th b dy wall In arious pecie gills a e attached at the neck on the ides of the thor and on the s d a d tip f the bdome In se er l pecies ch nymphal st u t r s pe s t the dults but d ot funct n

Adult t fl es h ld the r w g lo e to thei b ks wh e t rest or w lk The h dwi gs are pl ted a d h dden The ame Ple pte meaning pl ted w g mes fr m th habit Folded wi gs c t t te a st p n evolut n ne er a hieved by m yfl es or even by b tte fli



Fi pt o ( ) Nymph f P f h w g g ll t ba f l g (b) Ad lt of Pl o cy f th l g t fl (A H M g F ld B k f P d d St m Put m 1930)

flukes and tapeworms have given clearer insight into the host para ite relationship

Classification The following classification of the platyhelminthes is based on that of L Hyman with modifications Separate articles appear on each group

Phylum Platyhelminthes
- Class Turbellaria
  - Order Acoela
  - Order Rhabdocoela
  - Order Alloeocoela
  - Order Tricladida
  - Order Polycladida
- Class Trematoda
  - *Order Monogenea (Heterocotylea)*
  - Order Aspidogastrea (Aspidobothria Aspidocotylea)
  - Order Digenea (Malacocotylea)
- Class Cestoda
  - Subclass Ce todaria
    - Order Amphilinidea
    - Order Gyrocotylidea
  - *Subclass Eucestoda*
    - Order Tetraphyllidea (Phyllobothrioidea)
    - Order Lecanicephaloidea
    - Order Proteocephaloidea
    - Order Diphyllidea
    - Order Trypanorhyncha (Tetrarhynchoidea)
    - Order Pseudophyllidea (Bothriocephaloidea)
    - Order Nippotaeniidea
    - Order Cyclophyllidea (Taenioidea)
    - Order Aporidea

Tu bellaria This class considered ance tral to the other two is the most primitive of the phylum five orders are recognized The body is cylindrical or flattened and may be less than 1 mm to over 50 cm long The members are chiefly free li ing but commensal and parasitic species occur A cili ated epidermis may uniformly cover the body or may be restricted to the ventral or other surfaces Peculiar rodlike rhabdoids of uncertain function are embedded in the epidermis Characteristic color patterns are imparted to some species by chromatophores while other species contain ym biotic algae and are green or brown The order Acoela contains small marine forms lacking an enteron They dige t food within phagocytic mesen chyme cells and lack an excretory ystem tato- cysts are usually pre ent The order Rhabdoc ela consists of small marine or fre h water f rm with a simple blind intestine One suborder tl e Temno cephalida occurs as ectocommensals n fresh water animals The order Alloeocoela compr e mall marine or fre h water organisms with aclike or lobulated gut while the order Tricladida n sists of larger forms either marine fre h water or terre trial which have a three branched intestine (Fig 1) The order Polycladida ntain the ma rine forms of elongate or leaflike hape with few t many eyes near the tentacle and on the body mar gin Many inte tinal rami branch from a centr l dige ti e cavity above the pharynx

Trematoda This large class con i ts of para ites covered with a secreted cuticula Three subcla es or orders occur here (1) Monogenea found mainly as ectoparasites on cold blooded vertebrates ha e direct and simple life cycles (2) A pidobothria, endoparasites of invertebrates and vertebrates are characterized by their alveolated ventral attach ment surface and by their either direct or compli cated life cycle (3) Digenea endopara ites of vertebrates have two or more hosts involved in their life cycle (Fig 2) The intermediate ho t i a mollusk

Cestoda These highly specialized animal are parasites of most vertebrate classes The typical tapeworm subclass Euce toda consists of an at tachment organ the scolex and a series of imilar reproductive segments the proglottid Members of the other subclass Cestodaria are non egmented and occur in the intestine and coelom of lo er fishes the larvae occur in crustacean

In Eucestoda the ripe eggs or hatched ciliated larvae (coracidia) are ingested by intermediate

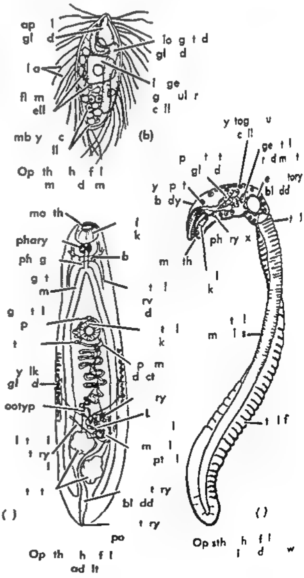


Fig 2 Stages i lif cycle of Op tho ch s f l ( ) Ad lt (b) M c d m ( ) C co a (R d ow f m ll Vogel Zo l g a 33

(1) the Pa ific bo d ha n f we tern North Amer ca (2) the North S a a ea of n thwe t rn Europe the Medit rr e n Sea a e f o thern Eu pe a d n rth rn Afr a a d the ntra o tin tal b ns of e tr l a d e stern Europe and so the As (3) th S wal k r g on f the Him laya Mou t n nd (4) the o stal reg n f South A tr l Ion o rocks a e h st p e served i m ntain u a a t rr st ial str ta ar be t known in th tin nt l nter s and m r ne beds a e mo t wide p ead n the tmental mar g s in the e of th c t l pl a d c nt e t l h l es Mo t of th m in r marg al Pho- ne t ata r l ti ly fl t ly ng and oc u near sea level but ru t l d t b ce h e appr i bly d form d som f the beds and h ve levated th m t ri h hts a f r ex mpl in the Apen nines f It ly a d n th P ifi B rd r eg on of N rth Ame c f om Baja Cal fo n to Ala k As m y a 5000 meters f I I c e trata present in pa t of th s P cific B rde reg on b t in gen eral the th k of the e beds app eci bly le s Th y co t n ari u pl es l d g s grou d w ter ph phat s nd cl y l me t ne nd other p od t

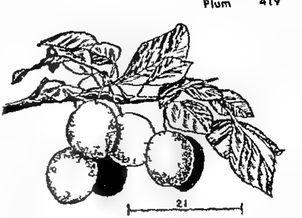
Pliocene t ta we f rst st d ed in deta l in the Med terranean reg on nd th s thes typ lo ality —th ea to whi h f renc i made fo ompa g rock in oth part of the w ld th t ar be- lieved to b f th am age He e th Pl cene is d ly s bd d d i t tw unt (tag) ach of wh h sh b ts a mar n d a t r st r l fa ies

Ma c G gn u th mode n Eu pean str t g ph r tat d i f to the Pl oce e f th Med terr nea rea that n othe t t g phic uni f the Tertiary n e cl ut th t f llows g th g t regr at th d f the M n the Pl oc ne f rmat f th reg on lway l e d s e t u ty n the lder f rmat o a d that th e d of the p d always m k d by e tr t of the e Th enclo ed betwe a tr s- gr o nd eg es the Pl o ene of the Med te r e n a e corr p d t a dm t ry cy l r d po t n l ri f llowed by pe d of e o whi h t a gu ted th Qu t nary Th gh th Pl o l m t d plac b phy l br ks i th d m nt ry o d phy al ha g k w t th pla e and d ffe e t a t f the ts i ba d t tly n p l tol gi l er l

Fauna Th Pl oce f una d t tly modern n l rv l i g typ f mammal echi o d pelecypod g t pod a d f rm f s r pre- se ted l dd t ma y f r n w e t t (b r toothed at g d l th a d glypt d t) m de p a p m nent l m t in th Pl oc n f u S I ISO OT Y L EO TO OGY [A H CH C E M]

Plum

Plum are shrub o am ll tree wh h b mooth k ed to e f u t also lled pl Th pl m s n n ent pe ies d t ng ba k ev ral th nd y ar



D m pl m (F m L H B l y Th St d d Cy lo- p d f H rt lt I 3 M m llo 1937)

Varieties Th plum in lude a wide ra g and v riety n origin tree a d fru t The e re four pri cip l gro ps (1) Dome ti a (*Prunus d m s t a*) of Eu p an origin (2) Insititia r Dam on plums (*P insititia*) of European orig n (3) Sal in (*P lic a*) of Japan orig n and (4) Am can plum (*P me ica a* and *P hort la a*) The Dome t cas are la ge me ty pru type plums lud ng Agen (Cal fo n a pru e) Re ne Cl ude Ital a Prun and Yellow Egg a d titute the p c pal fresh and dr ed p une of c mm e A p u e a pl m wh h w ll dry w th out poil ng Ins t tia r pr s nted by the Shr p- h and French ari t e e mall me ty fru ts grown pari gly fo jam Japa e plum a e typi cally ro nd dd h o y llow and juicy a d ar rep e ent d by uch ari t es a Ab nda ce Bur bank Be uty S nta Ro a Sat m a d Sh A e can pl m e mall wat ry fru ts of low qu l ty ep esented by D S t and P ttawatt mi nd teemed p mar ly for the ha d ne f the tree

Propagation and commercial production Plum r propag t d by budd on eedl g f th myr bal plum (*P unu c sif*) nd les ommo ly o the p ch nd rt in t ain of *P nu d m s ca* S GRAFTI OF PLANTS PEACH

The D me t ca a d Insit tia plums r sl ghtly ha d th n th p h the Jap n e pl m ha abo t the ame h rdi ess as the pe ch a d n t e Ame c n pl m are co s d rably h rd er th n the oth ieti e

T ee of th D me ti a nd D m o type grow to 20–30 ft re adapted t r l t ely heavy l d ar pl t d 20–24 ft part Tr f th Japa and Ameri typ s w to 15 or 20 ft are adapt d l ghte soil d plant d 18 ft p rt M t plum q i e cr p ll nati n (s REPRODUCTIO PLANT)

Comme cial p od ti n i th Unit d Stat i 1957 w 88 000 ton f J pan s type plums, of wh h Calif rn pr d ed 85 000 t ns a d 493 000 to of p u type plums f wh ch C lif rn p od ed on h lf R t rn t g ow s w e $197

established Recent flatfishe are classified in 6 families about 116 genera and nearly 500 specie They are e entially benthic inhabitants of continental hore waters but a few ascend rivers or are found in the deep ea Although most are tropical to temperate a few cross the Arctic Circle Flatfishes are of great economic importance and they rank high in the quality of their flesh *See* ACTINOPTERYGII [R M B]

Bibliography J R Norman *A Systematic Monograph of the Flatfishes (Heterosomata)* 1934

Pleuropneumonia like organism (PPLO)

The nature of the e organisms and their classification are uncertain They may represent a special growth form of bacteria which they resemble in many respects and as such have been placed i the order Mycoplasmatales A colony i hown i Fig 1 They include the malle t organi m capable of independent life and are comparable in i to the larger filterable viruses (Fi 2 and 3) Th name is derived from a di ea e of cattle contagi pleuropneumonia in which the fir t organi m o this type was discovered Seriou di ea e are al produced by organi ms of thi group in heep goat chicken and turkey As harmless apro phytes they are often pre ent on the mucou mem branes of animals and man and have also bee found in ewage and soil *See* MYCOPLA MATALE [L D

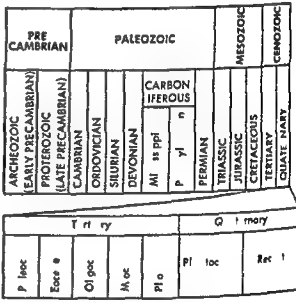
Fig 1 Colon of a rat PPLO on agar (From L D enes a d G Edsall P oc Soc E p B l M d 36 740–744 1937)

Fig 2 Electron m c og aph of a goat t a PPLO (From E Kl n b g N bel a d F W Cu kow J Ge M crob ol 12 95–99 1955)

F g 3 Elect on microg aph of a human st in PPLO (F m L D nes J Bact r ol 66 280–283 1953)

Pliocene

The youngest of the five major world wide di i n (epochs) of the Tertiary Period (Cenozoic Era) the epoch of geologic time extending from the en of the Miocene to the beginning of the Plei tocen or of the Quaternary *See* CENOZOIC TERTIARY



The term Pliocene was originally propo ed i 1833 by the British geologi t Sir Charles Lyell who divided the Tertiary into Pliocene (younge t) Miocene and Eocene and subdi ided Pl ocen into Newer and Older Pliocene The latter term were later abandoned and Pliocene i n w generally applied to what Lyell called Older Pliocen and the older part of hi Newer Pli cene

The Pliocene Series includes all rock formed during the Pliocene Epoch but the term is u ed most pecifically with reference to the ed mentar rocks which were formed during this interval o geologic time They c ntain the plant and an mal remains which are the primary ba e f r identification of Plioc ne age

Strata The Pliocene trata include all the common sedimentary types both marine and conti nental a well a intermediate one They are typically uncon olidated to poorly con olidated and are pre ent in many part of the world Par ticularly noteworthy are the n trata of

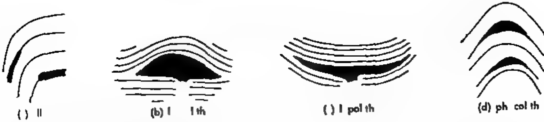


Fig 1 (-d) C ct f c c d t pl t

les f s ze r f rm b t do n t m lude t s e igneo bod (form d at th rf c f the e rth) The t rm fi st p p ed by H Cloos in 1928 h d been w d ly d pted by geologist *See* G A ITIZATIO

Pl t are c c dant o d o dant d p d g on wheth they a p rall l no p r llel t the d m a t f t res f th k they tr de The d t ct on h to be m de w th d e respect t sc le conco d e a b d way is g n rally ac e mp ed by d sc rd e i det il M o er a pl t b ly be da t r part of ts i t p th dd s da t oth p ts

Concordant plutons I tru e bod e f th type ge lly d d d t s ll l c ol th l pol th s d pha ol th b t the cl s fi at n i n t eces a ly compl t Othe form h e b e desc bed b t th n mes ha not fo d w de usag th f rm n m may b dded in th l t e m f these (s ch ph col th) may be d sc d d

Sll A ll i a pl t relat ly ar w dth b t e t e th the tw d me n truded es t ally p rallel t th pl r f t res th cl ed ock S ll g r lly w em l ced l g th bedd g pl ne f sed ment y ock (F g 1)

L c l th Th f rm mm ly t k to b t m h ped body w th ex roof d fl t fl truded i t bedded r cks (F g 1b) Th l y rs f rock the bl t l k t m p hed p rd t f rm d me Whe e ded the up- ured edg f the t t k l ye m y f m l r dg e lled h gb k *S e* LACCOLITH

Lopol th A l p l th la g a c h p d ody h ct zed p rt c la ly by e oof i d floo th l m f t f rm g cu t th th p oc f empl m t t b q tly i d d p d tly (F g 1c) Th gh le b d nt th n the pre edi g g oup number of la ge and st k g xamples are kn wn

Phacolith Phac liths re tructurally the re e f l p l th both r l a d flo r a e on ex pwa d (F g 1*d*) H w e phacolith a e g n rally small ompa ed to l pol th By defi tio the shap w s establ h d c n r e t with nd p sumably r lat d to the p oce s f i tru on a ill s bsequently deformed nt th sh p would not be a pha ol th *Ex mpl s of phac l th may b t* few t w rant clu ion n a gen ral la ific tion

Discordant plutons Cu rently used names in lud d kes tock b th l th v lcan nts and g d ke As with co co da t plut ns the l st n t c mplet the nam s h e bee used nd me co ld be add d ubt acted

D ke A d k s m l t ill o g n d n a e s app a ce the thick s mall com pa ed t the e t t a th oth tw d m n b t the body t n gre (ts o s) the f tu e of th e l st g ock (F g 2*a*) Dik ge r lly we empl ed l ng f actu ystem of f s tu e

St k A t ck a pl t n w th o ghly eq d me on l o s tion f lim ted ize b t a much gre t r g ne ally i d t m at th d dim ns on wh h d ar ly teep e t l (F g 2*b*)

B th lith Th f m most mply de cr bed a large t k th epa t n be g pl ed at bo t 40 m f c s s t on ea but w dely ed d fi t (by R A D ly 1933) l o t ted for both t k d bath l th that n floo could be d t rm d i fe d a d th u g i p eferred by s m g l g t (Fig 2 nd d) *Se* BATHOLITH

F lc t The e s e the ro t f l n p ed by by undergr u d e pl t (s VOLCA o) Th y e gene lly mpo t f e l i trus s d t us e f t d re compl

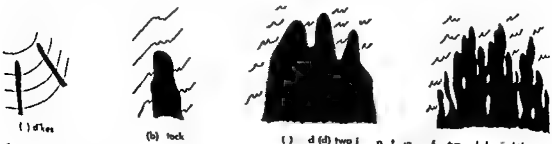


Fig 2 (-d) C se l d sc d t pl

ton for plums and $88 a ton for prunes *See* FRUIT (BOTANY) FRUIT (TREE) [H B T]

Plum and prune diseases Brown rot a fungus disease caused by *Monilinia fructicola* is the lim iting factor in production of plums under humid conditions Infected fruit decays rapidly and is cov ered with gray masses of fungus spores (*see* FUNGI) Punctures made by the plum curculio a common fruit in ect increase the risk of fungus in fection Control is difficult and mu t include meas ures for control of the plum curculio as well as the fungus Commercial production of plums and prunes is confined almost entirely to the Pacific Coast state where the plum curculio does not oc cur and climatic conditions are less favorable for development of the fungus

Japanese varieties of plums and their hybrids are so susceptible to attacks of the bacterial spot organi m (*Yanthomonas pruni*) that their com mercial production is likewise confined to the far western states where the organism does not occur *See* BACTERIA

Other fungus di eases are plum pockets (a form of the leaf curl disease) rust and scab These dis ea es u ually cause little damage

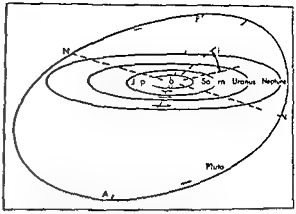
Diamond canker and prune dwarf are two impor tant virus di eases that cause prune trees to become unproductive Control involves removal of affected trees and use of virus free nur ery stock *See* FRUIT (TREE) DISEASES PLANT DISEASE CONTROL PLANT VIRUS [J C DU]

Pluto

The most distant known planet in the solar system It was di covered photographically on January 23 1930 by C W Tombaugh at the Lowell Observa tory where a systematic search for a trans Nep tunian planet had been initiated by P Lowell The presence of an unknown planet beyond Neptune and perturbing its motion had been predicted in dependently by P Lowell and by W H Pickering on the basis of an analysis similar to though less rigorous than that which had led U J Leverrier and J C Adams to the prediction of Neptune Pluto was found surprisingly near the predicted position However because of the estimated low ma s of the planet ome astronomers have questioned the a lidity of the original prediction

Pluto s orbit has a emimajor axis (mean dis tance to Sun) of 3 7 × 10 miles an eccentricity of 0 25 the large t of the major planets an incli nation of orbital plane to ecliptic of 17 3 al o the large t of the major planets a idereal revolution period of 248 4 years and a mean rbital velocity of 2 96 mi/ ec Pluto s large eccentricity cau es its di tance to the Sun to vary from 4 59 × 10 mile at aphelion to 2 76 × 10 mile at perihelion The perihelion is 4 9 × 10 miles le than Neptune s aphelion distance but becau e of the large incli nation of Pluto s orbit the two orbits d not inter ect *See* NEPTUNE PLANET

Pluto i vi ible only through large tele copes its vi ual magnitude at mean oppo iti n (that i when clo e t to Earth) i 14 The apparent di



O bit of Pluto A persp ct ve v ew to show the ncl o t on a d eccent city of the o b t *A* aphel on *P* perihel on *NN* line of nodes

ameter of its disk as estimated vi ually b G P Kuiper with the 200-in tele cope at Mount Palomar is about 0 2 and the corresponding linear diame ter about half of Earth s diameter With uch a di ameter and the mass about 0 9 (Earth = 1) de rived from the perturbations of Neptune the mean density would be of the order of 40 an improbabl high value On the other hand if the albedo is ab ut 0 2 a plausible value the diameter would be about the same as Earth s and the den ity about 5 but the apparent diameter should be 0 45 This di lemma had not been resolved through 1959

The theoretical average temperature is about 90 K The spectrum of Pluto hows no trace of specific absorption attributable to an atmo phere in particular no indication of *methane* although the superficial gravity would probably be large enough to retain a tenuous atmo phere of heavy gases

The light variations indicate that the urface of Pluto posses es dark markings and that the rota tion period is about 16 hours

Pluto has no known atellite Its unique orb t strongly inclined and highly eccentric uggest an unusual origin for example that Pluto may once have been a distant satellite of Neptune hich escaped through the effect of external perturba tions on the system

The discrepancy between the ob erved apparent diameter and the e timated mas f Pluto ha led to the suspicion that a trans Plutonian planet re mains to be found in the outskirt of the lar system but it would be very di tant and very faint and the chances of f nding it accidentally are ex tremely slight No sy tematic search f r such a planet had been made through 19 9 [G P K]

Bibliography H N Rus ell R S Dugan and J Q Stewart *Astronomy* rev ed ol 1 1945

Pluton

A general term in geology for a rock body f rmed by con olidation from a magma (molten m ter al) without reaching the surface of the arth or pos sibly by pr ce es of replacement (granit zat i g ing an end prod t n t readil d ting i hal) from that of the fr t nam m A n u ed the term includ r

'u(III) t Pu(IV) i rapid w th b muthate bro- ; te i o (III) d chromate iodate permang ate a d ce ium(IV) ion Reduct on of Pu(IV) t 'u(III) i rap d with iron(II) od de io s lfu s a id and nitrou acid Oxidation f Pu(IV) P (VI) low with bromate di hr mat pe nang n m and n t at io s The rates may be hanged markedly by complex ion formation In h p en e f moderate on entrations of sulfu ic ac d f r exampl oxidatio past the IV state very d ffi lt. Som lat vely rap d oxidat on re ct are l o known Ceric i n arg nt c ion and b muthate rapidly n idi e Pu(IV) to Pu(VI)

The i n of the d ff rent n id tion state ha e hara t tic olo Pu bl ue-v l t P rellow b wn PuO redd sh a d PuO^{++} p nk Like th r re ea th they al h ve char ct i tic absorpt pect a with sha p b rption ba ds The e ha been w dely d in th a aly is of pl t um lution to d t m e the amount of h dat state pre-e t

Preparation of the element M th d f r the *isol t n d pu ifi at n f plut n m make us f* the f t th t the eleme t n x t i a m ltipl ity f x dati n tat s n ch d ffe g in h m cal prop ert es Laboratory p at p c du h v been dev sed g arr er lve t e t act d o ha ge method Th fi t plant c le op *k n mpl yed t e ca i* b muth pho ph t and l th m fl de l m t rece t p o se *sol* t ext a t s mpl y d It h the ad a t ge th t t nly th pl t m but al o th ur n um f *the r a t* fuel m y b e d ly e er d nd de contam ated f m fi n prod t Some f th *m t mporta t* l e ts re l ted Table 1 *Co t ol l th* xtra t beha o obtai d by th o f d l nt f th l nt dd t on f alt *k t t* the queou laye a d the co t l f lu t pH l *Tabl* 1 a e l ted the d l t a d lt ing ag t e mm ly empl yed f th d ffe nt *sol nt* The beha f d ffe nt al e t tes th these sol e t n be ll t ated by f c t th r lati e d tr b t n c ffi ie t d fi ed th n tr t n of th m t l i th g i ph e d ded by the nt ati n in the q us ph (T bl) Th e t l af f th d tribut o- ffi ent w ll ch ng with c nd t b t th ap- p x mat r lat e al es w ll be ma t n d In th i d tr al p oc employ ng h e (th Red *proc* s) th n m f el i d l d nt a d Th s(t o d ed d the U(VI) d Pu(VI) x oe t acted f m the fi p d t Aft r bb g th he l y t m mp t es the sol t i pa d v n al m m t t w l i c t n ng duci n g t Th pl t n m l *rem* ed nt the aq eo l y Pu(III) d th u n um l ft the l nt a th tt i r oe ed By ces y l th pl ton m i p fied t th de d d gree

Th nd t) p oce mpl yi g t b tyl phosphat (TBP) th l ent (the P p oc ss) p tes in m h th ame m n Aft d- olut on of the f el el ment the pluton um fixed a Pu(IV) nd th ura um U(VI) The nit ic ac d onc ntr tion is dju ted a d the Pu(V) and U(VI) e t cted t 30% TBP in k ro n The l ent i w h d w th n t acid to *remo impuri* t The pluto ium then remo ed a P (III) by scr bb ng the l ent w th n t i ac d o ta i g a ed c ng g nt

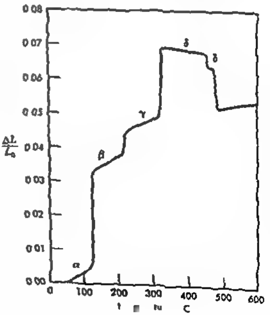
Pluton m met l n be p p ed by the educ t on f PuF w th c l i m m tal Pl t ni m m t l *d erves spe l me t n* b cau e of its q pr p rt s ft kn wn t e i t s x all t p form b low the m lting po t (639 C) Some f

T bl 1 Solve ts sed i the separation of pluto i m a d a ium from fi ion p od cts

Sol t (tri l n m)	D l t	Salting gent
M thyl sob tyl k t (H)	No	$Al(NO_3)$
T b tyl phosph t (TBP)	K rosin	HNO $Al(NO_3)_3$
D b tyl ethe f thyl glycol (C b tol)	N n	HNO
D b tyl eth f t tr thyl glycol (P t th)	N b tyl th	HNO
Triglycol d bl rid (Trigly)	N e	$Al(NO_3)$
Th yl trifl ro cet (TTA)	B t l	N

Tabl 2. D st ibution coefficients of u n um plutonium d fissi p od cts from it te solutions of 100-d y cooled ctor fu l

Sol	U(VI)	Pu(VI)	Pu(IV)	Pu(III)	F'n prod cts
H	1 5	7 6	$1 6 \times 10^{-3}$	$4 5 \times 10^{-4}$	6×10^{-4}
TBP	8 0	0 6	1 5	2×10^{-3}	2×10^{-4}



E p lo f h gh p ty pl t m d d t o f self h t g $L = 0 5$ (Aft E R J H)

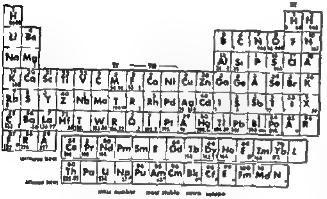
Ring dikes Ring dikes are arcuate dikes formed under special circumstances during the emplacement of stocks or batholiths they are known from a few widely separated places in the world

[J A N]

Bibliography M P Billings *Structural Geology* 2d ed 1954 R A Daly *Igneous Rocks and the Depths of the Earth* 2d ed 1933 C B Hunt P Averitt and R L Miller *Geology and Geography of the Henry Mountains Region Utah* USGS Profess Paper 228 1953

Plutonium

Chemical element number 94 plutonium Pu is a silvery white reactive metal of the transuranium series of elements The first isotope to be identified was Pu^{238} produced in cyclotron experiments by



G T Seaborg E M McMillan A C Wahl and J Kennedy The principal isotope of chemical interest is Pu It is formed in nuclear reactors by the process

$$U^{238} + n \rightarrow U^{239} \xrightarrow[23\ m]{\beta} Np^{239} \xrightarrow[2.33\ d]{\beta} Pu^{239} \quad (1)$$

Pu^{239} decays by α emission with a half life of 24 360 years Its fissionability makes it of importance in nuclear weapons and in nuclear reactors Minute quantities of Pu are formed in pitchblende and monazite ores by reaction (1) In pitchblende the uranium to plutonium ratio is approximately 10 1

Uses Plutonium is used as a nuclear fuel to produce radioactive isotopes for research and as the fissile agent in nuclear weapons *See* NUCLEAR FUELS REACTOR NUCLEAR REACTOR NUCLEAR (CLASSIFICATION)

Properties Like its neighboring elements uranium and neptunium plutonium exhibits a variety of valence states in solution and in the solid state In solution the known oxidation states are III IV V and VI Plutonium metal is highly electropositive The ions of the IV V and VI states are moderately strong oxidizing agents The ions of the III IV and VI states can coexist in 1 M perchloric acid solution

Because the oxidation potentials are so close in value pure solutions of intermediate oxidation state undergo disproportionation (self oxidation and reduction reactions) The most important equilibrium is that involving the disproportionation of Pu(IV) which can be written

$$3Pu \quad + 2H\ O \rightleftharpoons PuO \quad + 2Pu \quad + 4H \quad (2)$$

for which the equilibrium constant is

$$K_1 = \frac{[PuO_2^{++}][Pu^{3+}]^2[H^+]^4}{[Pu^{4+}]^3} \quad (3)$$

K_1 is calculated from the potentials to be 0.0089 for 1 M acid at 25 C In 1 M acid the solution resulting from the disproportionation of pure plutonium(IV) would be 72% Pu(IV) 18.6% Pu(III) and 9.3% Pu(VI) Although Pu(V) is unstable in molar perchloric acid it becomes increasingly stable as the acidity decreases In 0.1 M acid appreciable concentration of all four valence states may coexist in solution The additional equilibrium that must be considered may be written as

$$PuO \quad + Pu \quad \rightleftharpoons PuO \quad + Pu \quad (4)$$

The equilibrium constant K_2

$$K_2 = \frac{[PuO_2^{++}][Pu^{3+}]}{[PuO_2^{+}][Pu^{4+}]} \quad (5)$$

is 13 in 1 M perchlorate solution at 25 C The rate of attainment of the equilibrium of reaction (2) is slow and that of reaction (5) very fast A constant equilibrium state is not maintained over long periods of time because of the slow reduction in average oxidation number in solution caused by the reaction of the plutonium ions with the α-radiation induced decomposition products of the water

In solutions of acids such as nitric and hydrochloric whose anions form weak complexes with plutonium ions the relative stabilities of the different states are little changed Qualitatively it is known that univalent anions with the exception of fluoride form relatively weak complexes with the ions of all oxidation states Higher valent anions form relatively strong complexes In general the relative stabilities of complexes with a given anion decreases in the order

$$Pu \quad > PuO \quad > Pu^{3} > PuO$$

Complex formation will generally stabilize the IV state Hydrolysis reactions can also markedly affect the relative stabilities of the different states As in the case of complex formation the IV state is stabilized by hydrolysis Polymerization processes play an important role in the hydrolysis reactions Plutonium(IV) has been reported to form soluble polymers with molecular weights as high as 10

A large amount of information is available on the behavior of plutonium ions when treated with common oxidizing and reducing agents It is generally found that reactions which involve only changes from the III to IV or V to VI state tend to be rapid Reactions which involve the formation or destruction of the oxygenated ions of the V or VI states tend to be slow As examples oxidation of

P (III) t Pu(IV) is rap d w th B muthate bromate iro (III) d chromate iod te pe mang n te a d ce um(IV) i ns Redu tion of P (IV) to P (III) i r pid with i n(II) od de on lfu io a d and trous ac d Ox dation of P (IV) to P (VI) is sl w with bromate d chromate per m ng ate nd n tr te i The rates may be ch ged ma k dly by mplex ion f rmat n In the p nce of moderate ncent ation of sulfu ric d i r e ample oxidat on pa t the IV state i ery diffi lt Some relati ely rapid ox dation re t e al wn C ion a gentic i and b m thate r p dly ox dize Pu(IV) to P (VI)

Th s of the d ff t oxid t o states ha e ha ter stic colors I u s bl e violet Pu yell w brown P O reddish d P O⁺⁺ pi k Lik th are e rth th y l o ha e cha acters t ab pt n p t w th ha p ab orption b nds The ha e b w dely u ed n the analysis f pl t m m ol t n t d term e the m nt of e ho d ton t t p e e t

Preparation of the element Methods for the i ol t n and p fi t f pl t m m ke f the f t that th lem t n exi t i a multiplicity f oxid t n t te ea h d ffe i g in chem al prop ert Lab at y t on pr ed r h l de d u re l ent e t t d ex h ge meth ds Th fir t pl t c l pe a t mploy d th s bi muth ph ph te d la th m fl rid I m st r t p c es s l t t t mpl y d It h s the ad tag th t n t nly th pl ton m b t l the m m of the t f I m y b ad ly vered d de taminated f m fi n prod t Som e f th m t mpo ta t l e t list d Tabl 1 C trol f th t t n b h v bt d by th use f d l ent f the l e t dd t f alt ag ts to the q u l y a d th t l of l t n pH I T ble 1 ar l t d th d lue t d alt g ts mmo ly mpl yed f th d ffere t l t Th b h v f d ff re t l n t t with th l ts an b ll t t d by f r e t th l t e d t b t effi nt d fi ed s th n e tr t n f the m tal n th rgan ph e d d d by the o ce t t o the q ph e (T ble) Th a t l l f th d t b t o- ffi nt will h g w th d t n but the p pr x m t rel t v l w ll b m t d

I the i d t tal p s mpl y ng he e (the Red x p oc) th u m l l i d l d n tri d Th l t d i d d th U(VI) d Pu(VI) c ext t d f m th fis p d t Aft bb g th h o laye t m mpur i th l t p d l m m tr t e lut o ta g d g ag t Th pl t m m d t th q e l y a P (III) a d the ur m left th l ent a U(VI) Th q us l y th r x d ed d th e t t r pe t d By u y le th pl ton m pu fied t th d ed degree

Th i d t i l pr s mpl y g t b tyl ph ph te (TBP) th l t (th P x p es) pe at n m h the m man s Aft d

Table 1 Solve ts used i the sepa tion of plutoni m a d ani m from fi sion products

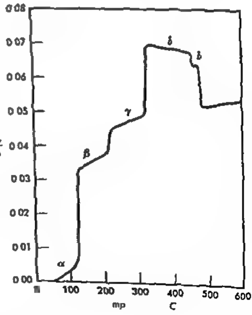
Sol t (t l am)	D l t	S lti g
M thyl isob tyl ket (H)	No	Al(NO)
T b tyl phosph t (TBP)	Keros e	HNO Al(NO)
D b tyl th f thyl glycol (C b t l)	No	HNO
D b tyl th ft t thyl glycol (P t th)	N B tyl th	HNO
T glycol d hl rid (Trigly)	N	Al(NO)
Th yl trifl roacet (TTA)	B t l	No

T bl 2. Di t ibution coefficients of ra i m plutoni m d fi io prod cts from nit t solutions of 100-d y cooled e ctor fu l

Sol	U(VI)	Pu(VI)	Pu(IV)	Pu(III)	Fission prod cts
H on	1 5	7 6	1 6 × 10⁻⁴	4 5 × 10⁻⁴	6 × 10⁻⁴
TBP	8 0	0 6	1 5	2 × 10⁻³	2 × 10⁻³

luti n of the fuel el m t the plut nium is fixed as Pu(IV) d the uranium a U(VI) The nitric ac d o cent tion is adj t d and the P (V) d U(VI) extract d i t 30% TBP i ke ine Th ol e t is w hed w th nitric a d t remo e imp i t es Th pl t n um i th r m ed a P (III) by scr bb g the s l ent w th nitri d ntai ng a red g gent

Pl t um m t l n be p p red by the red c ti f PuF w th lc um m t l Pl t ium metal d rves sp l ment o be e of ts u iq e p perties It is know t exi t in s llot pi f rms b low the m lt g po t (639 C) Some of



E p f h gh p ty pl t m d d t l ll-h or g $L_0 = 0\,5$ (Aft E R J tt)

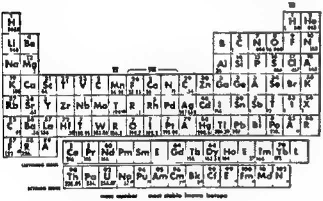
Ring dikes Ring dikes are arcuate dikes formed under special circumstances during the emplacement of stocks or batholiths they are known from a few widely separated places in the world

[J A N]

Bibliography M P Billings *Structural Geology* 2d ed 1954 R A Daly *Igneous Rocks and the Depths of the Earth* 2d ed 1933 C B Hunt P Averitt and R L Miller *Geology and Geography of the Henry Mountains Region Utah* USGS Profess Paper 228 1953

Plutonium

Chemical element number 94 plutonium Pu is a silvery white reactive metal of the transuranium series of elements The first isotope to be identified was Pu^{238} produced in cyclotron experiments by



G T Seaborg E M McMillan A C Wahl and J Kennedy The principal isotope of chemical interest is Pu^{239} It is formed in nuclear reactors by the process

$$U^{238} + n \rightarrow U^{239} \xrightarrow[23\ \text{min}]{\beta} Np^{239} \xrightarrow[2.33\ \text{days}]{\beta} Pu^{239} \quad (1)$$

Pu^{239} decays by α emission with a half life of 24 360 years Its fissionability makes it of importance in nuclear weapons and in nuclear reactors Minute quantities of Pu^{239} are formed in pitchblende and monazite ores by reaction (1) In pitchblende the uranium to plutonium ratio is approximately 10^{11} 1

Uses Plutonium is used as a nuclear fuel to produce radioactive isotopes for research and as the fissile agent in nuclear weapons *See* Nuclear fuels Reactor nuclear Reactor nuclear (classification)

Properties Like its neighboring elements uranium and neptunium plutonium exhibits a variety of valence states in solution and in the solid state In solution the known oxidation states are III IV V and VI Plutonium metal is highly electropositive The ions of the IV V and VI states are moderately strong oxidizing agents The ions of the III IV and VI states can coexist in 1 *M* perchloric acid solution

Because the oxidation potentials are so close in value pure solutions of intermediate oxidation state undergo disproportionation (self oxidation and reduction reactions) The most important equilibrium is that involving the disproportionation of Pu(IV) which can be written

$$3Pu^{4+} + 2H_2O \rightleftharpoons PuO_2^{++} + 2Pu^{3+} + 4H^+ \quad (2)$$

for which the equilibrium constant is

$$K_1 = \frac{[PuO_2^{++}][Pu^{3+}]^2[H^+]^4}{[Pu^{4+}]^3} \quad (3)$$

K_1 is calculated from the potentials to be 0 0089 for 1 *M* acid at 25 C In 1 *M* acid the solution resulting from the disproportionation of pure plutonium(IV) would be 72% Pu(IV) 18 6% Pu(III) and 9 3% Pu(VI) Although Pu(V) is unstable in molar perchloric acid it becomes increasingly stable as the acidity decreases In 0 1 *M* acid appreciable concentrations of all four valence states may coexist in solution The additional equilibrium that must be considered may be written as

$$PuO_2^{+} + Pu^{4+} \rightleftharpoons PuO_2^{++} + Pu^{3+} \quad (4)$$

The equilibrium constant K_2

$$K_2 = \frac{[PuO_2^{++}][Pu^{3+}]}{[PuO_2^{+}][Pu^{4+}]} \quad (5)$$

is 13 in 1 *M* perchlorate solution at 25 C The rate of attainment of the equilibrium of reaction (2) is slow and that of reaction (5) very fast A constant equilibrium state is not maintained over long periods of time because of the slow reduction in average oxidation number in solution caused by the reaction of the plutonium ions with the α radiation induced decomposition products of the water

In solutions of acids such as nitric and hydrochloric whose anions form weak complexes with plutonium ions the relative stabilities of the different states are little changed Qualitatively it is known that univalent anions with the exception of fluoride form relatively weak complexes with the ions of all oxidation states Higher valent anions form relatively strong complexes In general the relative stabilities of complexes with a given anion decrease in the order

$$Pu^{4+} > PuO_2^{++} > Pu^{3+} > PuO_2^{+}$$

Complex formation will generally stabilize the IV state Hydrolysis reactions can also markedly affect the relative stabilities of the different states As in the case of complex formation the IV state is stabilized by hydrolysis Polymerization processes play an important role in the hydrolysis reaction Plutonium(IV) has been reported to form soluble polymers with molecular weights as high as 10^{10}

A large amount of information is available on the behavior of plutonium ions when treated with common oxidizing and reducing agents It is generally found that reactions which involve only changes from the III to IV or V to VI state tend to be rapid Reactions which involve the formation or destruction of the oxygenated ions of the V or VI states tend to be slow A oxidation

In dd t on to tho e compound p ep red by a m l ne techniques, the r a larg number f compound that h e been prepa d from s l tion The mo t mportant f th a e g en in Table

S NEPTUNI I NU LEAR CHEMISTRY TR NSU RA IL I ELEME T [J C H]

B bl phy J J Katz nd G T S aborg *The Ch mist y of the A ti ide El m ts* 1957 G T S b rg nd J J Kat (eds) *The Act de Ele t* 1954 G T S al rg J J Katz d W M Man g (d) *The Trans ani m El nts* 1950

Plywood

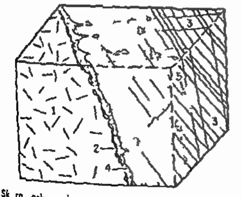
G ed he t t p o p c s m de of thr e r m e s g a d w od e e s (th n plyw ods) tw f u m r e r pl s a w d lumber o m lt ple bl ck re (co e plyw d) The cro gr n g of the pl e gr e plywo d m th greater tr ngth a d dimen o al tab l ty than the pla n ood from h h the pl a m d

Thin h d o d e e r l e tly ftw d co es r wid ly u d n furn tu a d for w ll and l ng p n l Plyw od mad of pens ve wood mploy d exten i el i te f rm he th g bff r g b r and rat Molded d p e ed or b g m ld d plywo d ar b e m ng increa ngly mp t nt in the m n f tu of mall bo t h ll a r ft parts hat d s m lar shell lik o tru t n S e LUMBER MA UFACTURE [C C O]

Pneumatolysis

Th alt atio f r ck by the a t n f m gmat g Th g a omp y m gm ti t u on d p rm at th nt d d ocks alo g fi su es d other) f lea t re t S METAMORPH I META OMATI

P mary m gm t a e a e d a d th fore react read l w th l e t t f rm k rn k App eci ble am nt of h y m t l t s ally pre



Sk rn ock d p m t lyt t A M k l g od ite 2 g t z d b d f g dior s (pp r d? 3 (m t 4 g t k or im d t cont r g me 5 b d F drod) w l t t c pp l t d l g t sect f fi d b dd g pl (Aft A K pf m W H N h D D p t R f t d t St uel F t P n t U w P 1942)

nt as chlori le flu ride or lf de) are a ci ated w th the magmat ga e Th e are capt re l by th limest n and retained as depos ts of ka n r cks t or s In ther place tl hea y metal are depo ted in granite chi t cau ing the formati n of g ei en *See* GREI EN SKARN

The f ll w ng l t i dicates c mmon pneumato- lyt c min als c ncentr ted n lime t ne of tl e O lo reg on

M t ls	*M ne als*
Fe	And a l te hed nberg te oxi l e an l sul f l c i on ore
Zn Cu Pl	Sphaler t ZnS ch lc pyrite CuF S_2 g len PbS
Mn	Andr i t hedenberg te rhod te (Mn Fe Ca)S O
B Ag	B muth nite B_2S galena spl l rite
Mo W	M l l le te M S_2 cheelite $CaWO_4$
Co A Sb	Cobalt te CoAsS arsen pyrit FeAsS t muti n te
Be Ce	H lvite (M Fe Zn) $Be_3Si_3O_{12}S$ vesu v an te allan t $(Ca\ Fe)_2(Ce\ Al\ Fe)_3$ S $O_{12}OH$
M talloi l	
Si	*S l cat s i skarn qu tz*
F Cl S	Fluor te CaF_2 cap l te ulf d e re
B I T	Ax n t apatit phe

Additi nal pn matolyt m neral a e tho of the h mit gr p and by pneumatoly of hal t urm f n t paz m vit phlog p te and l th i m m a Lu ullian te i a t urmalin zed granit

In cl ion t m y be empha ed that l me stone espe ially su ceptible to pneum tolyt tact met morph sm re lung t f rm t n of *karn* k nd ften eful or dep (Ir n Sp gs Utah Ma y Idaho Ye gton Nevad C ep n d l Oro M co) Th minerals oft dev l p w ll formed rysat l and th depos t bel g t the be t kn wn *mineral* c rren es n the wo ld (F ankli Furn N J Clifton M renc A z Aue ba h Ge m ny Bergg esh b l B t H ng ry Co cepcion d l Oro Mex co) S l te o k n t u ally as i te s v ly l te d h t by t du t n of flu r n a d l th um and by th f rmat on f gr i en f ld p s m y ch n nt t p z zinnwaldit or th r m as T n i omet m ntr du d f rm ng e t ite SnO Othe t t duc d m ner ls in arg ll tes f r in stan m lybd n te p t t l yl

S m t m ten e bo on p eum t ly m y pro- du e datol te axi te and ra e m n r ls like koto te $Mg_3(BO)_2$ flu b r te Mg (BO) (F OH) l d w g t (Mg Fe $)_2$Fe BO nd oth r [T F W B]

Pneumococcus

The maj r ba t r l au e f loba p umo i Th m c o g sm s efe red to a *D plo cus p u m a* (t be Str pt a a of family Lact l a c lla a) S LACTOBACILLACEAE

Morphology P m cur as p f al

Table 3 Properties of plutonium metal

Phase	Symmetry	Density g/cm	Temperature of phase transition C	Linear expansion coefficient $\alpha \times 10^6$	Resistivity $\times 10^6$ (ohm-cm)	Temperature coefficient of resistivity†
α	Monoclinic	19 816		50 8	145	− 1
			122			
β		1 65		38 0	110 5	−6
			203			
γ	Orthorhombic	1 19 17 14		34	110	−5
			319			
δ	Face-centered cubic	15 9		−10 0	103	+
			453			
δ'	Body-centered tetragonal	16 0		−.0	105	+45
			4			
	Body-centered cubic	16 48			114	−
			639 5			
Liquid		16 5		50		

$\alpha = \frac{1}{L}\ \frac{L}{T}$ $\quad \dagger \frac{1}{\rho}\ \frac{\rho}{l} \times 10$

its physical properties are given in Table 3 Particularly interesting and puzzling are the contractions which the δ and δ' phases undergo with increasing temperature (see graph) noteworthy is the fact that for no phase do both the coefficient of thermal expansion and the temperature coefficient of resistivity have the conventional algebraic sign If the phase expands on heating the resistance decreases A number of alloys of plutonium are known Among these are alloys with beryllium lead uranium chromium manganese iron nickel and n mium

Principal compounds A large number of compounds of plutonium have been prepared Reaction of hydrogen with plutonium metal yields at least two well defined hydrides PuH and PuH The common oxide is PuO It is formed by ignition the hydroxides oxalate peroxide and nitrates any oxidation state in air at 870–1200 C. It crystallizes in a face centered cubic structure (density 11 44 g cm) It has been extensively used for gravimetric analyses of plutonium A lower oxide Pu O is known One of the most important cla of compounds is made up of the halide Pr perti of the known halides and oxyhalide are given Table 4 The hexafluoride is a low melting lo boiling compound of high volatility resembli NpF_6 and PuF It is a strong fluorinating agent Condition for the preparation of the fluorides illustrated by the equations

$$PuO_2 + \tfrac{1}{2}H_2 + 3HF \xrightarrow{600°C} PuF_3 + 2H_2O$$

$$PuO_2 + O_2 + 4HF \xrightarrow{0°C} PuF_4 + 2H_2O + O_2$$

$$PuF_4 + F_2 \xrightarrow{750°C} PuF_6$$

The other halides are prepared by a variety method Treatment of PuO with powerful halogenating agents such as CCl PCl_5 and SO yields PuCl $PuBr_3$ and PuI are conveniently made by the action of the anhydrous gases HBr and HI on plutonium metal

A number of other compound are kno Among these are the carbide silicide sulfide and nitride These are of interest because of their refractory nature Among these are PuC, Pu C PuN α $PuSi_2$ β $PuSi_2$ PuSi PuS Pu S_3 Pu_2S

Table 4 Plutonium halides and oxyhalides

Compound	Color	Melting point C	Density	Crystal structure
PuF	Pu pl	14	9 3	Hexagonal
PuF	Pale brown	103	7 0	Monoclinic
PuF	Red brown	50 5		Orthorhombic
PuCl	Green	60	5 0	Hexagonal
PuBr	Green	681	6 69	Orthorhombic
PuI	Green		6 9	Orthorhombic
PuOF	Metallic	1635	9 6	Tetragonal
PuOCl	Blue-green		8 81	Tetragonal
PuOBr	Green		9 0	Tetragonal
PuOI	Green		8 46	Tetragonal

Table 5 Some insoluble inorganic compounds of plutonium precipitated from aqueous solution

Oxidation state			
III	IV	V	VI
$Pu(IO_3)_3$ PuPO O H O $Pu_2(C_2O_4)_3 \cdot 9H_2O$	NH_4PuF_5 $Pu(OH)_4 \cdot xH_2O$ $Pu(IO_3)_4$ P O H O $Pu(HPO_4)_2 \cdot xH_2O$	KPuO CO	$NaPuO_2(C_2H_3O_2)_3$

}ndu l w th actı p eum occal ı fections of all types and l-o w th certain streptococcal r ther fect Some mino non type-specific protect on aff rded by ant bodie in thı soluble ant ge de- ed from certain st ıns This factor als forms a port of the Fo m or heterophil a t gen SSS a ont act on fo type sp ec fic oluble c p la polysaccharid As l ttle as 0 001 mg of th mat l from me typ produce a t bodie the bl od th t e t either d re tly with th spe ific carbohydr t of th c psul o with th whol o gan m th s p otect g gai st infect n by r gan m f th s m type Int ade mal ı j ctı n of SSS int p t nt over ng from p um nı f the sam typ gı e mm d ate (wh l a d erythema) local ak ct o s he m f m p tient ac tely ıll th p m occal ı f tions l oc tai C ea t ing prot n ppar ntly ot an antibody that ıs l o f d ma y other infect ns and feb le ıll ess s.

Types Pne m ococc be d ıded nto more tha 77 typ s n the b f the d ffe es ı their h ghly polymerized ımm nolog ally d tınct poly a h des The pecif c ty of th type de pe ds o their h m l c mpo t n and t ctu Th ha been w ked ut f r a few types Some f these poly cchar d are losely r l t d ımm no- l g cally a d chemic lly to s m la co t ed ı cert ın y a ts, f ngı th hen ıcell l s of m ny pl t d tr blood gr up A subst e a d t th f om oth r ba ter l sp cies ı bly *Kl b l pneum ıa B cillus anth a* nd *Hem ph lus fl n* Th e l o ol gıc l c t s betw ıı ta types ot bly between II a d V nd b t e III a d VIII The ıfic p ly ch ıde e als b) et ı hyd oly s by zym s p od ed by a u l ga m ma fthe n ymes a e h hly typ pec fi

Variants I the p t descriptio f m rph l g ı l nt ı mo c l col nıes we e b ed th r appe ce n the f c of l d med Th t rm mo t d w ıı m ooth (S) ugh (R) a d m d (M) P obl ms ros b f the ter gım of c lo s nt med t b tw m d d mooth a d mooth nd gh R Au tr n (1953) p d th t the d fi tıo of m ph l g c ıa t b mad t cellular th th n t lo- l lev l II d fi ed th morphol g c arıa ts n d tabl c nd t th f ll w g nonfilam nt s, c p ul ted (S) n f l m t n ap l ted (R) fil ment cap ul t d (?) and fil m t n p lated (l R) Th fila m t f rm diff f om the nfil m nt u ın th t th ell f th fil m t f m f l to s pa t afte d n g g ı t h s of p u mococc wh no III me to f rm ppe as gl cell d pl c r sh t h n All the p- l ted f m ha p fi p ly a l d the n p l t d d ı R gh t a wh l r a tral t d l k type pe fi ty m y be p d ed by g th n h m l g u type- p fi nt e m th t ı rum ta ng ant bodı of the m p umocc l type R gh t n a w ll fi at k lled t s ha e b en tra f rmed to r l t mooth f rm [f p oth th n th g l on by growth eith r ın sol tı ns f the type pecif c r g nı m r n l tı s of de xyrıl onucleic acid derı ed f om the type-specific organ m Type tran formatı ns can al o l e mad ın mıc ınocu lated with mixtures f l th dead enc ulated or g nı m of one type and lı g ıgh nonencap u l ted organı ms f a other De xyrıb nu leic acid ha e al been u ed t tran form traın en sıtı e t ant biotıc such a pe ıcıll n a d trepto- mycı ınt ant b otic res stant tra n with ut em ploy ng e po re t the e antıb otıc Ne rly all the 20 variant theor tıcally ded ce l l y different com bınat ons f th fou m phol g c variant l ve al been produced ı th ı ma ner Th ı anal gou to recombın tıon of ınd pend tly h rıtable characte ın exually reproduc ng f rm *S e* BACTERIAL GENETICS

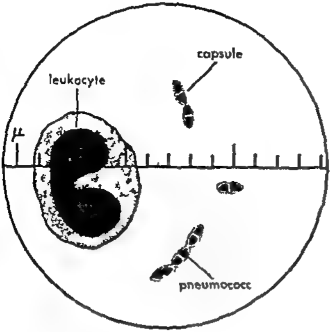
Pathogenicity Pneumococcı occur ın the upper respır t ry t t of apparently healt y guinea pıg rabbıts h rses ıı l es d g monk y and l uman Ep zootics of p umococ al pn um n nd f ther *loc l or systemic* pneumococcal infect n o c r ın monkey guıne pıgs and ats but are not the o of hum n ı fection (*see* PNEUMONIA) Epıdem cs of pneumo al pneum ıa al cc r n human m tly ı closed tıtutı n S me of the ep d mics h e b prevent d r their sp d halted by mmunization w th k lled acc nes r w th pecific c b hyd ates of th ame pneumoc l types In ma p moc ı may be f u d the up p r respırat ry t t of early all ındı du l at *me time* or othe P eum ct are the principal c e f lob r pneumon b t m y l o pr d ce m g t pericarditis and p t t a well as ı fect of the pleura middle ear a d acces ry n al ı S me f th ı infe t on a accom p ed by o of th bl od st e m ept m Th m t lty u t e t d fections h gh b t th ha be ı ma kedly educed by th u e of tib t S BACTERIOLOGY MEDICAL. [M F]

B bl g phy III A t Morphol g c m t n p m cu *J E p Med* 98 21–34 35–40 1953 R J D b (ed) *B ct ri l d Mycotic I f cti s of M n* 3d d 1958 M Finl nd R cent d c ı the pıd m l gy of p eumoc ccal ın f t n *M d ne* 21 307 344 1942 M He d l be g r Th f rma t n f a t bod es ın m n aft ı t n of p u m occ l polys ch ıde *P c N tl A d S U S* 43 883–887 1957

Pneumocystosis

A d e f m n au ed by a spo zo n *P umo cy t* Th micr rga sm rıg n lly re p rted ts n 1912 ha b e gly ec g d w de p e d h man p th gen s ce 1953 b efly th gh th ın tıg tıo f O J o- a d coll b to s O ly n p s re ed n a m ls a d m d a dı gly th r ıs a ppos t th t the nfe t on m y p f m n f th g oups to nother Of po ible mpo ta e th l f d lt rr ers d at ng the ınf ctı n to ı fa ts

Mo t e ep t d thu fa h b e fatal n cur gı nf nt o ery yo ng ch ld en The lung



Pneumococcus in sputum (From A B Sabin J Am Med Assoc 100(20) 1585 1933)

at proximal sides and pointed at distal ends A capsule envelops each pair or chain of cocci this capsule may have a uniform periphery or may show indentations between the twin cells or between pairs The organism is nonmotile and stains gram positive unless the organisms are degenerating or dead *See* Bacterial motility Gram's stain

Cultural characteristics Pneumococci are fastidious in their nutritional requirements which include many amino acids vitamins minerals and carbon sources The organism grows best in enriched media containing serum or blood and in the presence of oxygen being aerobic It also may grow anaerobically in which case it probably derives oxygen through a flavin containing enzyme system It produces hydrogen peroxide that may hinder or prevent growth this may be overcome by adding substances having oxidation reduction action It grows uniformly in liquid media Lactic acid and in some strains formic and acetic acids accumulate in the culture medium increasing the acidity and limiting growth this may be overcome by adding glucose to the medium and by neutralizing the acid with sodium hydroxide Growth is optimum at 37 C and the organisms die rapidly at 55 C

On blood agar the organism produces small water clear flattened and (later) umbiliform colonies that are surrounded by a greenish zone of hemolysis indicating methemoglobin formation The organism contains intracellular proteolytic lipolytic and carbohydrate-fermenting enzymes these readily produce autolysis that is dissolution of the organism Viability of the pneumococcus can be preserved in partly desiccated animal tissue like mouse heart or spleen or by lyophilization which is rapid freezing with vacuum drying *See* Lyophilization

Identification Pneumococcus closely resembles ... of *Streptococcus viridans* but can be

Solubility in bile The addition of a solution of either bile salts or sodium deoxycholate to a young broth culture or to suspensions of organisms at a neutral pH will cause lysis of the pneumococcus and a turbid pneumococcal suspension will clear rapidly This action is complete in 5-10 min and probably represents accelerated autolysis It occurs without regard to specific type or colonial form *S viridans* will not lyse under this test

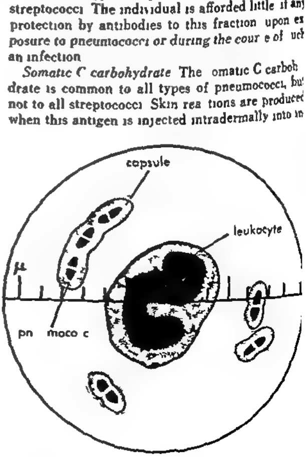
Quellung reaction Swelling of the pneumococcus capsule is induced by mixing the type-specific antiserum (serum containing antibodies) prepared from rabbits with a suspension of the organisms This differentiates the type as well as the species *See* Quellung reaction

Pneumococcidal agents Pneumococci are vulnerable to the usual germicides and antiseptics growth is inhibited by many quinine derivatives especially optochin (ethyl hydrocupreine) and also by most sulfonamide drugs (*see* Antiseptic Sulfa drugs) They are susceptible in vitro and in vivo to many antibiotics the most effective is penicillin Although resistance to these antibacterial agents has been induced by repeated subcultures in subinhibitory concentrations resistance has not been shown to develop during treatment of pneumococcal infections

Antigens Pneumococci contain three major antigens *See* Antigen

Somatic protein antigen This antigen is common to all types of pneumococci and to certain streptococci The individual is afforded little if any protection by antibodies to this fraction upon exposure to pneumococci or during the course of such an infection

Somatic C carbohydrate The somatic C carbohydrate is common to all types of pneumococci but not to all streptococci Skin reactions are produced when this antigen is injected intradermally into in



Quellung reaction Type II pneumococci mixed with ...

duals w th ctive pneum cocc l nfecti ns of all es a d al o w th e t in streptoc ccal or th r ct s Some min r no typ specific pr tect on ff rded by nt bod es to th ol ble antigen d d f m ert i a ns The fa t r al o forms a t n of the Fo ssma r hete ophil antig n SSS nt act o for typ specific ol ble p la polysaccha de As l ttle as 0 001 mg of mater l f om ome types p oduces antibodies the blood that re ct ither di ectly w th the spe i bohydrat of th c ps le r with the whole gan m th s p ot cti g ag st infect o by or m of th s me type Intradermal injection of S t pat ts co ri f m pn umon a f the m type g e mmed te (whe l a d erythema) al k n re t o Se um from pat e t acutely ill th pneumococe l nie t on also co ta n a C ea t g p otein ppare tly n t an ant body that s lso nd n ma y othe i fect ns and febr le Ill sses

Types P umoc ci be d vided i to m e an *77 types* the ba of the diffe en s n e h ghly polyme ed mmun log cally d ti t ly c h des The specifi ty f th types de end on th r chem c l omp it o a d tr tu e h ba been ork d o t fo few type Some f hese polysacch *ides* a lo ely relat d mm no g lly a d ch m c lly to s m lar s onta ed c rtain y as a f ngi th hem ellul e f m ny la ts d t blood group A subst n and to h f m oth b cteri l p e tably *Al b lla* p e mo a *Bacill* s h i a d *Hemo phi* s *fl* e The e e) s *rolog cal c o* t o b tw n certa t p ot bly b tw e II d V nd b t III d VIII The p sfi poly h id a al ubj t to hyd oly i by e zymes p od d by ar u o l o g m m m ny l th me h ghly typ spe fi

Variants I *the pa t de* ipt ns f m ph l g e l a ia t in p m) lone w ba d o th ppea n e th u fa e f l d med a Th term mo t d we smo th (S) o gh (R) a d m d (M) P bl m o e b *ause of the* ec gn t n of e l i te m d ate b tw m d d m th a d mooth a d ugh R A t *ia* (19 3) p opo d that th d fi t n f morph l gi t be m d t a ell l th r th t l n l l el H d fi d th mo ph l g a a t g d table d t s the follow g a afilam nt u p l t d (S) o fil m nt u nc p l ted (R) fil m t c p l *ted* (?) a d fil m to ap f ted (al R) The fil m t f m d ff f *om the* fil m nt th t the c lls f th fil me t s f rm f l t I t aft r di g g t h n f p eu mococ wh r o e fil me t s f m ppe s gle c ll d plococci h rt f s All th p l ted f rr h spec fi p ly h d s th ap ul ted d t R ugh t ai wh h e a rul t d lack typ p fi ty m y b p d ed by g th i h m l g u ty p c fi a t um sh i m nt ng t b d e *f the* ame p umoc l typ R gh st a well s h t k lled i h h n tr f rmed to l *nt* mo th f rms ther th the g l ne by growth e ther in oluti ns of th type pecific or ganisms or in lutions of de xyribonu leic ac d de ived from the type pecif c orga i m Type t n fo mation an al o l e made in mice in cu l ted w th m xt res of both dead encap ulated r ga i ms f ne type a d li ng ro gh n nenc p i lated o ga isms of a other De xyr b n cl c a id ha e al b en u d t tran fo m train s n a e to antil iotics uc as penicill n and strepto mycin a to nt bi tic re tant strai s without em ploying expo re to the e ant li tic Nearly all the 20 variants theo et cally ded i ed by d fferent c m bin tion of th f ur m ph log c ariant ha e al been prod ced i th s man er Th i an lo g us to rec mb at on f i depend ntly h ritab le ch racters in exually prod cing f m Se BACTERIAL GENETICS

Pathogenicity P eumoc cci ccu *in the upper* espi atory t act of apparently healthy *guinea pig* rabbits hor s calve d gs monkeys nd human Ep zootic of pne mo cc l pn um ia and of other local or ystemic p eumoc ccal infection occur in monkeys guinea pigs and rat but re not the s urce of h man infect ons (se PNEU IONIA) Epidemics of pne moc cal pneumonia al o occur in h man mo tly in clo d in titut on S me f the epidemics h ve b e p ented or their spread halted by imm n zation w th k lled a cine r with pecifi ca bohyd t f the same pneumococcal type In ma pneum cocci m y be f und i the up p r re p ratory tract f ne ly all ndi iduals s me t m or ther Pn umoc ci are the pri pal c e of lobar p m but may al o prod ce m ingit pe ic d tis a d perit n tis as well a i f tion f the pl ura m ddle a nd acce *ory* na l s u Some f these infection a a com pan ed by si n f the blo d *tream or epti* c m Th m tality i u tre ted f t ons is high but this h b ma k dly reduc d by the of ant b ot cs S BACTERIOLOGY MEDICAL [M F]

Bibl g phy R Au t a Morph log c var a ti in pn moc c *J E p Med* 8 21 34 35–40 1953 *R J D b* (d) *B cterial and My t f f t s f Ma* 3d d 1958 M F nl nd Rece t ad c i the p d miol gy of p um coccal in f t n *Md* 21 307–344 194 M Heidel be g Th f rm t n of ant b d n man fte t je t f pn umoc ccal poly a h ides *P o N tl A d S U S* 43 883–887 1957

Pneumocystosis

A d e e of m n caus d by spo z n *P m cystis a n* The micro g n m ig nally r po t d n at i 1912 h s b e i r a ngly re g d widesp d h m n path ge n 1953 hiefly th o gh the v t g t o s f O J ro- ec nd c ll b t rs O ly on pe i recog d n a m l d m and rd ngly tl e e i a ppo t n that the *i f* tion may pa f om ne of th e gr ps to an th *Of po s ble* imp t th le of d lt a ie n d s m n i g the nf to toi f ts

M e po t d th s f r ha e b en fat l urr ng f t o ery young ch ld e The lung

lesions are conspicuous and distinctive and the entity plasma cell interstitial pneumonia has been attributed to *Pneumocystis* Satisfactory therapy and control remain to be achieved *See* PARASITOLOGY MEDICAL [D W]

Bibliography J Vanek O Jirovec and J Lukes Interstitial plasma cell pneumonia in infants *Ann Paediat* 180 1–21 1953

Pneumonia

An acute or chronic inflammation of the lung tissues occurring in humans and in many animals Pneumonia in humans may be caused by numerous microbial immunological physical or chemical agents It may also be associated with many systemic disease Any or all parts of the lung may be involved with the inflammatory exudate filling the alveolar air spaces of one or more lobes as in lobar pneumonia or the smaller segments in lobular pneumonia It may be disposed in and around the bronchi in bronchopneumonia or may be limited predominantly to the interalveolar areas as in interstitial pneumonia Pneumonia may be a primary di ease or a secondary event in other diseases

Known causes and diseases Pneumonia may be caused by bacteria fungi various parasites and rickettsiae and also by mi cellaneous conditions like allergy expo ure to chemicals and foreign bodies

Bacteria The following organisms ause pneumonia

Pneumococci of various types cause pneumococcal pneumonia

Staphylococci that are congula e positive cause staphylococcal pneumonia

Hemolytic group A streptococci cause streptococcal pneumonia

Klebsiella pneumoniae types A B and C cause Friedlander s p eumonia

Bordetella pertussis causes whooping cough often with pneumonia as a secondary infection or complication

Haemophilus influenzae causes influenzal pneumonia Type b strains of *H influenzae* a e usually found in infants the strains found in adults cannot be typed

Pasteurella pestis cau es bubonic or pneumonic plague

Brucella species cause brucellosis In acute brucellosis pneumonia may occur as a complication

Coli aerogene organisms may cause pneumonia incidental to a systemic infection

Salmonella species cause systemic infecti ns including typhoid fever Pneumonia may occur as a complication

Meningococci cau meningococcal meni gitis with pneumonia a a secondary infection or c mplication

Bacillus anthracis cau es anthrax One f rm pulmonary anthrax has a high fatality rate if not diagno ed early

Mycobacterium tuberculosis on occa ion, may cau e acute tuberculous pneumonia

Mixed infections that is infections with more than one species of bacteria or with bacteria and viruses may cause pneumonia *See* BACTERIOLOGY MEDICAL

Fungous infections Infections due to fungi may involve the lung and cau e pneumonia in moniliasis, actinomycosis blastomycosis cryptococcus hi toplasmosis coccidioidomyco i nocardio is, and others (*see* MYCOLOGY MEDICAL)

Parasitic diseases Infections with protozoa or helminthes may have pulmonary manife tations often acute in such di eases as trichinosis malaria amebiasis Lei hmaniasis (kala azar) toxopla mo si chistosomiasis paragonomiasis clonorchiasis, and filariasis (*see* PARASITOLOGY MEDICAL)

Viruses The known viru es which may cau e pneumonia are influenza A (including A ian type) A and B psittacosis (ornithosis) lymphocytic choriomeningitis variola (mallpox) varicella (chicken pox) measles adenovirus type 4 (and possibly other types) lymphogranuloma venereum and feline pneumonia Of probable but un proved viral origin are the pulmonary invol ements in cytoplasmic inclusion di ea e of infant in fectious mononucleo is and the o-called primary atypical pneumonia (PAP) or viral pneumonia (*see* ANIMAL VIRUS)

Rickettsial infections The include Q fever epidemic typhus (including the recrudescent form or Brill di ease) Rocky Mountain spotted fever *fievre boutonneuse* South African tick fe er and probably others *See* RICKETTSIOSES

Miscellaneous The following pneumonia ha e less common or ill defined etiologic agents Loeffler s eosinophilia (allergic pneumonia) rheumatic pneumonia lipoid pneumonia (from lipids and oils as oily nose drop) inhalation or a piration pneumonia (f om chemicals gase blood and other foreign bodies) pulmonary hemo idero is (associated with hemolysis of red blood cell usually from a systemic disorder)

Complications The bacterial pneumonias ma sometime cau e destruction of parts of the lung by ab cess formation or may involve the pleura in an empyema or sterile effusions Inflammation and dilation of bronchi (bronchiecta is) and pread of infection to rem te organ not unu ual Fortunately however most common pneumonias heal by resolution leaving lung structure and function little changed

Viral pneumonias may have s perimpo ed bacterial infection

Therapy and prognosis Treatment is pec fic f r the cau ative agent chief rel ance i n antimicr bial agents *See* ANTIBIOTIC CHEMOTHERAPY

The course and outc me depend on the cau e and al o on the a ailabil ty and proper u e of specific therapy [M F]

Bibliography R Heffr n *Pneumo ia ith Spec al Ref enc to Pneumococcus Lobar Pneumonia* 1939 H A Re m nn *Pneum*

Pneumonitis

An typ cal p umon s a ed by one f se eral l e use of th l mpl gran l m j ttac s p The e r ba oph l e gent which h been pl ed in ubd n nd e ll d pne mon ti t They l e cau ed pneumonitis in man mi e c t h p goat d cattl In m c th a q t wh ther th ar res ded in the oc l m h g tested tl pirat ry tract l the expe im ntal a imal ed f t lat o Th re i l q ti n wheth th e solated f m ma e pe ifically dapt d or whethe they a p it c i u of except nal i ulence and kn The p bl c he lth g ifi ance n t k wn Se Ly TRITO RA ULO I PSIT T CON CR LP [K F ME]

Podicipitiformes

Th d of b ds c ng th i gle f mil Pod p tid e th g eb Long th ught to hare a mm n c t with th l n (G i form) th g b w b l eved t h e e l ed l l ke adapt t i d pendently lo d in nd i imm g Th legs im la ly et f ba k n h dy ith omp e ed bl d l ke ta i Th toes f g ebe a n t bb d h w r b t ar in d id lly b d d a d l bed Th pl m e i d a d lk a d the t l i d m nta v Many pec es h e lab t nd ft j et c la f m l q at rt h p d pl v Alth gh highly d pt d f q at c l f m t g b s e t ng fl r a d the n p a e mi at v Th i fl htl p c e *Ce t p lma m c pt m* f und i Lak T tic c the A des The f m l a h f lly mopol t n S A E

[K.C P]

Podocopa

A b d r f th o d O tr da in wh h th memb ha hell th t w th ut a p rm e t l o ap rtu e The h lls f d ff nt p c ry s h p a d ulpt r B th p r f t e u ed f r l omot the w mm ng cra l ng Th m nd ble is well de l ped d t lly p d d w th p lp f fou p d m re Th p lp l o h l h f t at t l The h art b t A s mpl eye o o ll fre que tl p t E ch m ill d d w th l g r p to y pl t The e e fo p r f p r l p nd g fi t c d d th d th i l g a d th f a

Extant ostracods F r f mil f th P d ec gn ed b ed th st t e f th th a l p d the p ce r al nce d d g ee f d l pm nt f th d l m s. Th fam l es th Cyp da Da w uld Cyth d e d B l da

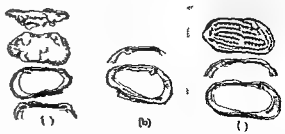
C p d Th f m ly lud both m nd fr h w t g er i wh h all th th c l g r d ent Th fir t th ic pp d g mod fied f m i t n d th d p d t of this leg n the mal f rm a p el en tle p lp The thi d leg t b nt d r ally and is u ed in keepi g the body and inner rfa e of the shell free f f reign mat ter The abdom nal ppendage and f r l ram each h e tw claws nd tw a r l In the Cypridop t ae the r mi are red iced t flagella lik etae The Cypridae how def nite ea l cy l s S me pe ies occur ly in a itum and tl rs n the spring or mmer Organi ms th t inhab it permanent bod es of water may l e tw r three gener tion a y pecie livi g t temp rary p d a d d t he g ner lly ha ly a i gle g erat n a year The life pan v ries with the pe c and w th cl matic c nd ti t ar d th t live in perm nent b d e of wat r g ner lly h e l nge l f pa s th n th e inhab ting temp r y p ds a d d tche

The f mily Cyprida is d ided i t e ght ul families wh h e w dely di tributed M t g era nd num ou sp cies are Holarct c r c m poli tan

Da i n l da Th s family ha the fir t tl ra ic a pe dag modified f m sticati n while the e nd nd third tl a leg re m l r nd adapted for crawl ng The anten e a e with t w mming t e Th f cae a e c mplet ly l k ng th l dy t m nat g n a singl c ne l aped p ject n Th f male ipar u that i be r li ng yo ng A gle genus *Darus* f i kn w w th tw p e pr e tly e gni ed Only *Da i ula tet so i* B dy a d N rman wh h bit the l tt m f la ge f f wat r l kes h be n ol rved n N rtl Amer c

Cyth ida Th are p ncip lly marin f rms The nten f m mlers f this f mily are w th ut nat to v tae and the th ee p f th c e l g are s m lar he ad pted f awl ng The fu al am r red ed a d the d ct s eja ula t iis i b nt S me pe s a e i ipar u Spe e f th ge s *E to yth* li a mm n al n the g lls f r pe f rayfi h

Ba d ul e yh d ida The r nt rely m e and p e s h ll of fi m e tency Th al es e nsp u ly q al with the left be g the l g The ante n are w ll dev l p d but re n t adapted f r w mm g The thr tho-



( ) Ol g yth f ll U d Sh b) J a cyth f d w th t m d t h g (b) *Al t yth* al t (B g t) Eoc e cyth cyth t d w th l b d t h g ( ) L g m o- cyth g f L R y c cyth e t d w th mph d t h g

lesions are conspicuous and distinctive and the entity plasma cell interstitial pneumonia has been attributed to *Pneumocystis* Satisfactory therapy and control remain to be achieved *See* PARASITOLOGY MEDICAL [D W]

Bibliography J Vanek O Jirovec and J Lukes Interstitial plasma cell pneumonia in infants *Ann Paediat* 180 1–21 1953

Pneumonia

An acute or chronic inflammation of the lung tissues occurring in humans and in many animals Pneumonia in humans may be caused by numerous microbial immunological physical or chemical agents It may also be associated with many systemic diseases Any or all parts of the lung may be involved with the inflammatory exudate filling the alveolar air spaces of one or more lobes as in lobar pneumonia or the smaller segments in lobular pneumonia It may be disposed in and around the bronchi in bronchopneumonia or may be limited predominantly to the interalveolar areas as in interstitial pneumonia Pneumonia may be a primary di ease or a secondary event in other diseases

Known causes and diseases Pneumonia may be caused by bacteria fungi various parasite and rickettsiae and also by miscellaneous conditions like allergy exposure to chemicals and foreign bodies

Bacteria The following organisms cause pneumonia

Pneumococci of various types cause pneumococcal pneumonia

Staphylococci that are congulase positive cause staphylo occal pneumonia

Hemolytic group A streptococci cause streptococcal pneumonia

Klebsiella p eumoniae types A B and C cause Friedlander s pneumonia

Bordetella pertussis causes whooping cough often with pneumonia as a econdary infection or complication

Haemophilus influenzae causes influenzal pneumonia Type b strains of *H influenzae* are usually found in infants the strains found in adults annot be typ ed

Pasteurella pestis causes bubonic or pneumonic plague.

Brucella species cau e brucellosis In acute brucellosis pneumonia may occur as a compl ca tion

Coli aerogenes organisms may cau e pneumon a inc dental to a systemic infecti n

Salmonella species cause systemic infecti ns in cluding typhoid fe er Pneumonia may ccur as a complication

Meningococci cause meningo occal meningitis with pneumonia as a secondary infection or complication

Bacillus a thracis causes anthrax One form pulmonary anthrax has a high fatality rate if not dia_no ed early

Mycobacterium tuberculosis on occa ion, may cause acute tul erculous pneumonia

Mixed infections that i infections with more than one species of bacteria or with bacteria and viruses may cause pneumonia *See* BACTERIOLOGY MEDICAL

Fungous infections Infections due to fun i may involve the lung and cause pneumonia in monilia is, actinomycosis blastomycosis cryptococcu hi toplasmosis coccidioidomycosis nocardio is and others (*see* MYCOLOGY MEDICAL)

Parasitic diseases Infection with protozoa or helminthes may have pulmonary manife tations, often acute in such di eases as trichino i malaria, amebiasis Leishmaniasis (kala azar) toxopla mosis schisto omiasis paragonomiasis clonorchia i and filariasis (*see* PARASITOLOGY MEDICAL)

Virus s The known viru es which may cau e pneumonia are influenza A (including A ian type) A and B psittacosis (ornitho is) lymphocytic choriomeningitis variola (mallpox) aricella (chicken pox) measle adenoviru type 4 (and possibly other types) lympho_granuloma enereum and feline pneumonia Of probable but un proved viral origin are the pulmonary invol ements in cytoplasmic inclusion di ease of infant in fectious mononucleo is and the so called primary atypical pneumonia (PAP) or viral pneumonia (*see* ANIMAL VIRUS)

Rickettsial infections The e include Q fe er epidemic typhus (including the recrude c nt form or Brill s di ea e) Rocky Mountain spotted fe er *fiev e boutonneuse* South African tick fe er and probably others *See* RICKETTSIOSES

Miscellaneous The followin_ pneumonias have less common or ill defined etiologic agent Loef fler s eosinophilia (allergic pneumonia) rheumatic pneumonia lipoid pneumonia (from lipids and oils as oily nose drops) inhalation or a piration pneumonia (from chemicals a e blood a d other foreign bodies) pulmonary hemosidero is (associated with hemolysis of red blood cell usually f om a systemic di order)

Complications The bacterial pneumonias may somet me cau e de truction of parts of the lung by al ce s formation or ma in ol e tl e pleura in an empyema r sterile effusions Inflammation and dilation of bronchi (bronchiecta is) and pread of infecti n to remote organs is not unu ual For tunately however mo t common pneumonia heal by re olut on lea ing lung structure and function little changed

Vi al p e monias may ha e superimpo ed bacterial infection

Therapy and prognosis Treatment is pecific for the cau ati e agent chief eliance i on anti micr bial agents *See* ANTIBIOTIC CHEMOTHERAPY

The c urse and outcome depend on the cau e and al o on th availability and pr per use of specific therapy [I F]

B bliog aphy R Heffron *Pne monia ith Spe ci l R f nc to Pneumococcus Loba P e mo ia* 1939 H A Re mann *I n m*

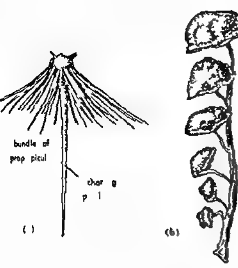


Fig 2 D p-s Poe 't le d ( ) Cl d h o l g p 5500 m t s (b) E p p h ll g 15 m (f m Hym 1940) (Aft R dl y d D dy 1887)

f d ı ll eas a d range f m t d l w ters t de ths of t le t 5500 mete s

F il po ges w th skelet ns omp rable t thos of R cent po il cle d are c ttered th gh the f il r co d fr m Cambr n time Un d bt d p e losel r d sp cules a e k own f m T n a y d p t See DEMOSPONGIAE [W D H]

Poeobioidea

A ph l m p po ed by W F h n 1946 f r n le p es P b us m Heath A r t eal t dy f th part lar p c re aled t t b n b a t p l) h t [C B C]

B bl g phy H Heath A e e t g l k b t een th Annel da and th E h ro d (G phy e m r) J M phol 49 223–249 1930 G E P kf d H tol g l a d h t ch m cal ob erva t n p an l t l d *Poeobius m* H th J M phol 80 287 319 194

Pogonophora

A g p f m l ga ded th s gle cl f th phyl m B h at They ha a te iz d by th f ll g f t r Th long te b d co t f th ee gment The two nt r r egme t f sed t f m an ante ı reg Th ıs p t d b a d ph gm fr m th l g t u k g g deds th d egm t Th t k ı bd d d ınt a p I et n o t ng f sh rt met m r po t n f llo ed by l o m ta m r p rt d p ta l ctı n wh h h bee n d d t be nd l m t m E h segm nt ha p at f m b dy ty a d th fi t gm t h e l mod t wh ch may r p esent e t ry o g n The c l m f the s d egment is w th ut d ct E t the th d has ell dev l ped c l m du ts wh h rv as g du ts f the ngle l g ad Th r ı m th an d ge t al S m pe es m y eed 6 in hes in l ngth There are f m one to 223 tenta le on the first egment Setae may ccur in gr ups the e are q ite different fr m annelid t

A ga gl n ma f ner c ll ı ituate l in a cephal c l le in the fir t egment and a l ıgitud n l n rve cord in th ep ıde mı l e n tl e ıd re ga ded a d r l

There ar l g t udınal d r al a d ntral l l d els nd a ve tral heart Blood ı d ı fl w forward in the tral ve el and back in the d r l

The exe ar eparate The te t are en rm a d with th r d t fill th entı e p terı r l lf of the trunk In fem les the ar es c jy the n t r r half f the tr nk The ggs are larg few in numbe elongat b late ally ımmetri al an l l a l) y lked Clea age ı t tal un jual and d t rminat It ı ne ther ıpıral n r radial but u ıq ı t th gr up Th e ı n l la t p re l ı t the a ımal p le becomes nter or The coel m ı ent r co lie nd the three egments bec me dı t t ea ly There n free wımm g larvae in the pecıe de bed

The P gon ph ra hav been btaı ed only fr m th ea b tt m a d lly at great depth l egın ning with the d c ery f I m ll sab lla by P U ch ko I 1933 he f und thı spec e in th Sea f Okh t k at depth f 3500 meters Ma y pec mens h since b taken many a both arc tic and t opı al They occ py lamell ted chit n lik n b ching t bes a d are pparentl d ntary The mod f feeding ı l ghly c nj c t l bec u f the al e f ll t nal alimen t y tructu ally f nd in higher mal that a n pa ıt c It ha bee p p d that the t t f c tch fin partı cul te m tt r wl ı h ı dı gest d e tra ellul rly

Tw rde s re r g ized the Athe anephria nd th The eph which tain fo r famil e d e en ge r Cha a t s of taxon m c value re th dhe e pl t l t on the sk th bridle d the t ta l I d ffere t ge r th bas of th tent cul w t e ther ır ıl h r ho h ped r p ral

At fir t on de d to b p lychaet d et ap rt s a cl by K J I a s in 1937 the P n pho a n w g n ally t ted a phy l th B ch ata Th re cl ly el ted t th Ent t a d Echinod m cho dat c mple (D uter t mi) S e ANIMAL KINGDOM ATHE CA EPHRIA BR CHIATA CLEAVAGE EMBRYO IC CO LO I ENTEROPNEUSTA OILAI THECAN PHRI [T H B]

Poinsot s method

A m thod f de b g by m f ge met l n t uct the mot o f a gid l dy with n t fi d spa e d with e to que o m m t t g on the b dy b t th fixed p t If a ı d body ı n tr n d t r t t bo t mooth fi d x d r no m ments e c pt th e d e t th a ea t o s th m t n ıs s mply on of o

Compound hinges in Ostracoda

Location	Type of hinge					
	Lopl odont	Merodont	Entomodont	Lobodont	Schizodont	Amphidont
Left valve						
Ante ior	Groove	Loculate groove	Loculate groo e	Loculate pit	Biloculate socket	Socket
Anteromedian	Rid e	Denticulate rid e	Short dentate ridge	Lobate boss	Bifid tooth	Conical tooth
Median	Ridge	Denticulate ridge	Long denticu late rid e	Smooth or denticulate bar	Denticulate bar	Smooth or denticulate bar
Poster or	Groove	Loculate groove	Loculate groove	Loculate groove	Loculate socket	Loculate socket
R ght valve						
Anterior	Ridge	Dentate rid e	Dentate id e	Lobate boss	Bifd stirpate tooth	St rpate tooth
Anteromedian	Groove	Locellate groove	Sl ort w de loci late groo e	Loculate pit	Biloculate socket	Socket
Median	Groove	Locellate groove	Long narrow locellate g oo e	Smooth or locellate groove	Locellate groove	Smooth or locellate groo e
Poste ior	Ridge	Dentate id e	Dentate d e	Dentate ridge	Lol ate reni form tootl	Lobate reni form tooth

Afte P C Sylveste Bradley

racic appendages are similar in tructure and all are adapted for locomotion The caudal rami are very small and extremely mobile The ejaculatory ducts are lacking *Bairdia Nesidea* and *Bythocypris* are the principal genera in this family Species have been collected from marine hab tats in widely eparated geographical regions [F F]

Extinct ostracods The Podocopa (Ordovician Recent) have many fo sil repre entati es both marine and fresh ater The superfamily Cytheracea in particular is abundant in the Me oic and Cenozoic and has many taxonomic divisions Nearly half of the fo sil species described belong to this taxon

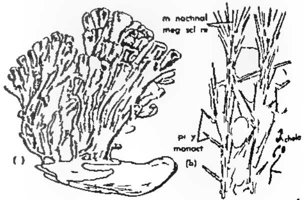
Hingement which is important in their classification may be either simple with a gro ve in one alve accommodating the edge of the other or compound with the hinge of each valve di ided *into three or four elements Six types of compound* hinge are di tinguished (1) loph d nt (2) merodont (3) entomodont (4) lobodont (5) chizodont and (6) amphidont This eries is more o less morphogenetic and certain evoluti na y line following it have been di covered In general tl e anteromedian element de eloped econdarily and the terminal elements became dentate and then fu ed changing from a ridge and groove to a tooth and socket arrangement [R V K]

Bibliography E Ferguson Studie of the ea onal life history of three species of f esh water O tracoda *Am Midland Naturalist* 32(3) 713–727 1944 R W Pennak *Fresh water Invertebrates of the United States* 1953 G O Sar *An Account of the Crustacea of Norway* vol 9 1928

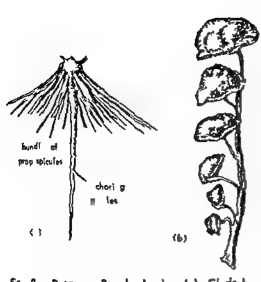
Poecilosclerida

An order of sponges of the class Demo pongiae in which the skeleton includes two or more type of mega cleres each localized in a particular part of the sponge colony Frequently one type of mega clere is re tricted to the dermis another t pe oc curs in the interior of the sponge Sometime one category is embedded in pongin fibers a econd category usually spinose protrudes from the fiber at righ t angle Spongin is alway pre ent but var es in amount from pecies to pecies Micro clere are usually p esent often everal types occur in one specie A wide ariety of micro clere cate orie i found in the order but a ters are ne er pre ent

In shape poecilo clerid po ges are encru ting ma i e lobate or branching Deep ea pecies often have bizarre sh pes Sponges of this order are



Fg 1 ( ) Mc oc a p oll a (b) Sp cul to of th m p g (Aft Hym 1940)



Fg 2 D ep- Po l l d ( ) Cl do h *l g p* 5500 m t (b) *E p p h ll g* 1 00 m t rs (f m Hym 1940) (Aft R dl y d *D dy 1887*)

fo d n all a d ra g fr m t dal wate t d pth f t] a t 5500 met r

F l p ■ with kel ton mpa able to th e f Rec nt p c l cl r ds te attered th ough the f l ec d f m Camb an t mes Un d bt l p il l r d p cul are known f m T rt y depos S e DE to PONGIAE [W D H]

Poeobioidea

A ph l m p po ed by W F h n 1946 f gl p es P b s m s H ath A it l t dy of thi part l r p ies ev l d t t be a berra t p ly h te [s c]

B bl g phy H He th A t ng l k t th Ann l da a d th Ech r le (*G phy e m (a)*) *J lf ph l* 49 223-249 1930 C E P kf d ll tol g al d h torhem c l b rva po an b a t n lid *P b us m* s H th *J lf ph l* ■ 287 319 1947

Pogonophora

A g p f an mal r g ded th ngl cla f th phyl m B h t Th y h r t d by th f ll w g f t Th el ng te body t f th ee egm t Th tw t gm nts r f ed t fo m nt g n. Th epa t d h d ph agm f m th l g trunk gion r g ded th d gm t Th t k bd ded pre n l ecto con t ng f h rt m t m port f ll w d ty l ng n met m n port a d ■ ta n l r t on wh h h bee d ed t he ec d r'l m t m r Ea h egm t h ra t oel m body a ty d th fi t gment h oel mod t wh h may p- resent n t ry o g n Th oel m f th ec d s gm nt w th t d t l t th th d ba w ll des l p d oel mod ts wh h rv a g od t f th gl p f g d Ther n m th a d gest n l S m ■ tes m y t e d 6

m l es n l ngtl Tl ere are from ne t 223 te ta cles n the fir t gm nt Setae may occur in gr up tl e e are q tte d ff ent fr m anneld s tae

A gangl onic ma f nerve cell s tt ated t a ephal c lobe in the fr t s gm nt and a l ngit di nal nerve c d s tl ep d rmi l e n the le re ga ded a d r al

Tl e a e long t d nal l r al an l v ntral l lood e els and a entral heart Bl d is aid t flow fo ward in the v ntral e el and ba k n the d r l

The xes r epa at The te tes are en rmous a d with ther duct fill th entir p teri r l lf of th trunk In f male th c arie oc py tl m t r ll lf of the trunk Tl egg ar large f w in n nb r el ng te bil terally ymm tri al and l ea ily y lked Clea age i total inequ l a d d terminate It i n itl e pi al n r radial l t uniq ■ t thi gro p Tl e i n bl t pore l t tl e an mal p l become nter or The c el m s e t ro elic and tl e tl ree egment bec me d t n t ly Tl re a no fre wimming larvae in tl e j e i d bed

Th P g ph ra ha ■ l een obtai ed ly fr m the e b tt m and u ually at g eat d pth l gin ning with the di co ery of *L m ll b lla* by P U ch k In 1933 he f u d thi peci s n the Se f Okh t k at a depth f 3500 m t s M y peci m n h e in been taken n ma y ea both r t a d tropical Th y occupy l mellated h tin lik nb nching tubes and re apparently de t y The mode of f ed g is highly ny c t al be u e of the b en f all i tern l al n t tru tu es lly f u d highe an mal tl t a e para t c It ha b n pr po ed tl at the t nt cles at h fi e pa t ul te matt r which i d gested extr ll l rly

Tw d a co n zed the Ath c erh a nd th Th an ph wh h e t in f ur famil d es n g n r Cha te of ta m c alue a th lhesi pl telet on the kin the bridle nd the t ta les l d ffe t g n ra th ba e f the t t c la w e the lar h r hoe h ped r p r l

At f t de ed to be polych t and t p rt a la by K Jol an n i 1937 tl P g ph r w g nerally ■ ted a a ph l m th B a h ta. They are losely related to th E t p eu t nd E hi od *rm-cho d t* ■ mpl (D t t m) S ANIMAL KIN DO ATHE C NE HEI BRACHIATA CLEAVAGE E IBRYONIC COELO E TEROPNEUSTA OVUM THE ANEPH [T H B]

Poinsot s method

A m thod f describ g by m n f geom t l truct the m t o of a r g d b dy w th po t fi d n pa nd w th zero t qu n mo- m t ct ng o the body b t th fi ed p nt If a *ig d body* tr ed to rot t ab t a smooth fi ed nde n m ment except th du to th x re cti n th motion simply ne of *on*

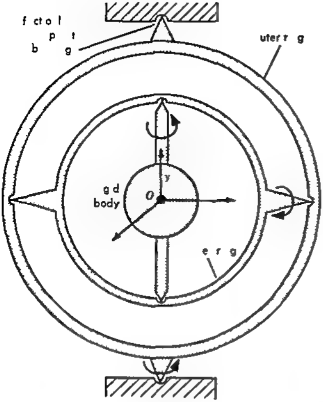


Fig. 1. Cardan suspension. Point O of the rigid body is fixed in space while the body is free to rotate about any axis in space under no external moments.

stant angular velocity. If however the body is constrained to move with only one point fixed in space, the motion, even with no moment acting about that point, is much more complicated. Furthermore the motion in this latter case is identical to that of a rigid body relative to its own center of mass, and it is therefore a more general type of motion for those cases where zero or negligible moments act about the center of mass. Such a body might be a top spinning on a frictionless table in a gravity-less system, a body mounted within a Cardan suspension, or a spinning rocket flying in space outside of the atmosphere but in a gravity field. See CENTER OF MASS.

Cardan's suspension. Consider a heavy body mounted with only one point fixed, constructed from light rings in an arrangement known as Cardan's suspension. In Fig. 1, point O is the fixed point, and it is assumed that the frictional torques can be made negligible and that the mass of the suspension system compared with the heavy body is negligible.

Let O be the center of a coordinate system composed of the principal axes of the body x, y, z, with unit directional vectors $\mathbf{i}$, $\mathbf{j}$, $\mathbf{k}$, respectively.

The vector angular velocity $\boldsymbol{\omega}$ and vector angular momentum $\mathbf{H}$ of the body are

$$\boldsymbol{\omega} = \omega_x \mathbf{i} + \omega_y \mathbf{j} + \omega_z \mathbf{k} \qquad \mathbf{H} = I_x\omega_x \mathbf{i} + I_y\omega_y \mathbf{j} + I_z\omega_z \mathbf{k} \tag{1}$$

where I_x, I_y, I_z are moments of inertia about the x, y, z axes respectively, and the products of inertia are zero about the principal axis (see RIGID-BODY DYNAMICS). The kinetic energy of the body is constant and is

$$T = \frac{I_x\omega_x^2 + I_y\omega_y^2 + I_z\omega_z^2}{2} \tag{2}$$

The angular momentum $\mathbf{H}$ is constant in magnitude and direction. Its magnitude is given by

$$H^2 = (I_x\omega_x)^2 + (I_y\omega_y)^2 + (I_z\omega_z)^2 \tag{3}$$

From (1) and (2)

$$\boldsymbol{\omega} \cdot \mathbf{H} = 2T \tag{4}$$

Ellipsoid equations. If now a line OA, called the invariable line, is drawn in the fixed direction of $\mathbf{H}$ (Fig. 2), and OB is the vector angular velocity $\boldsymbol{\omega}$ at any instant, then the line BC drawn perpendicular to OA determines line OC such that

$$OC = \frac{\boldsymbol{\omega} \cdot \mathbf{H}}{H} \tag{5}$$

From (4) and (5)

$$OC = \frac{2T}{H}$$

Therefore C is a fixed point and the plane through C normal to OA is a fixed plane, called the invariable plane. The terminus of ω (point B, Fig. 2) moves on the invariable plane during motion of the rigid body.

If point B is given coordinates x, y, z, then

$$\boldsymbol{\omega} = \mathbf{i}x + \mathbf{j}y + \mathbf{k}z$$

and Eq. (2) becomes

$$I_x x^2 + I_y y^2 + I_z z^2 = 2T \tag{6}$$

Equation (6) is the equation of the Poinsot ellipsoid which is fixed in the rigid body, tangent to the invariable plane at B, and with center at O. The semiaxes are given by

$$a = \sqrt{\frac{2T}{I_x}} \qquad b = \sqrt{\frac{2T}{I_y}} \qquad c = \sqrt{\frac{2T}{I_z}}$$

As the body moves, the ellipsoid rolls on the invariable plane

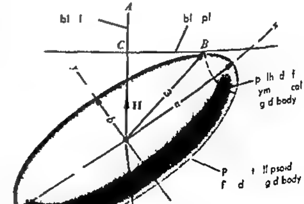


Fig. 2. Poinsot ellipsoid.

bl pl e be ause it has an a la elocity vec t r h h terminat t B the p int of c ntact f th llipso d a d pl e (e F 2)

The point B i c ll d the p le of th x s of r t t The l f this p le the ell p id w called by L. Poin t the p lh d a d th l cus on th ta g t pl ne th herpolh de

The r lting m t o in g er l q te com pli ted exc pt whe the P s t ll p oid a f of r l t If the i able pl e w e r p ese ted by a heet f pap and f an ll p id g e by Eq (6) we e n t cted c ated with ink d oll d th paper h ld ng center O fi d the nk o ld t e ut herp lhod curv 0 j m g the fi d po nt O t all po t thi urve the p e of th w tor w ld re lt In th w y th m t o f the g id b dy unde no m m ts c be l ed a d ep ent d

[R E B O]

Bibl g phy H G ld tei *Cl s al M h ic* 19 0

Point

I ax mat g om t y ally mplet ly und fin d (prim t) el me t lth gh the a e ax o t n f g met y wh ch th p pe t po t th t e des d r g e by p t l t ll t ate m try wh h l e is nut el m t p i t may b d fi ed la e es th t nf rm t e ta equ em t (p t) I -d m al met i a lyt p t m try poi t may d fi ed s n der d apl f mb I a lyt je t p t m try f d m i th t d t f the c ll d nfi t d l p t ec mpl h d by i a p t a der d (+1) tuple of mbe n t all e o d ide t fy g p t x x x) (y y y y) f d iy j = p y with = 1 2 + 1 d $\neq 0$ The d al p t th (+ 1) t pl f mb th th (+ 1) t e S ANA TIC GEOMET Y GEO IE RY EUCLIDEAN [L M BL]

Point source

d e g r d t n t s t t d fi e a pt all d the p t th t s ur g d fi te pos t but n t on p the d at p p g tes d ally t ht l n h h the me th ng ph l wa) m th p t e t f gy d d th t th t ty f th d t nd a d t n e ely th q a f th d t m th e N ph l r t lly them t l p t b t f d t n s ffi e tly g mp d t the d m f th e the e q l w m y b g d ppr mat o I VE SE SQU RE LAW

[T H H]

Point contact diode

A sem nd t fi g th b f rmed et p ll p pa d m d t d m t l po t t p od th t l

t n Th ntact ually ma ntain d l y mechan c l pre e b t t s m n tance it may l welded or b nded The r tifying ct n m pl that the re tance f th ntact is ignifi antly gr at f r ne di ect n f applied oltage (re er d recti n) th n f r th ther (f rward dire t n)

P nt c nta t d des l ave l een w dely ed in rad nd t le n a d m t tal ly n c mput r nd n mi rowa d tector and ultr h gh f e q ency m xer

When er a metal emi d t r c ntact s made n el ctr l ba rier gene ally e i ts l et een the tw O ly specially p pared hm c c tacts how no b rri r Thi l rier imp de the fl w f m j ity arr s (S e SEMICONDUCTOR f r defin ti of maj ity arr e s d di i n of ndi cti ty type) In an n typ em c nduct r th maj rity electr e immol liz d l y the b rr a d a l a which re d s the mi d ct r p ti e w th re pect t th m tal repel the p iti e h le (elec tro a an s) t th m t l Very little c rrent fl w nde th d t n and the e tance high If th n typ em c d ct t egat with r pect to the met l m t f the ele t o s are till mm bi l ed by th ba te b t l le n n w nte fr m the met l d a r lat ely f g curre t fl w that low t n i pr e t F r p type mi n d t the b rr r mpedes h le and the l i po la iti e e ed f the h gh a d l w re tan nd t

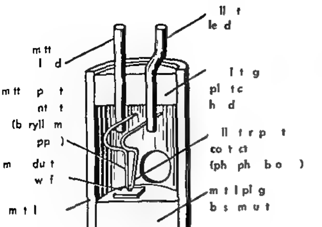
The m ll phy cal e of the p i t contact f es h gh rrent de s ty in the n ghb h od f th p nt The ur e t d t b ti n n th m d t g s r e t a sp e d i g e t n e i e e w th the b r er The f rwa d u ent s lim ted by th ta ce whil the erse cu r nt i l mited by the ba The sp e d g r tan e t d ly d a w th i g f rw d rre t a f he t d the nje tion f m o ity s S TRANSISTO

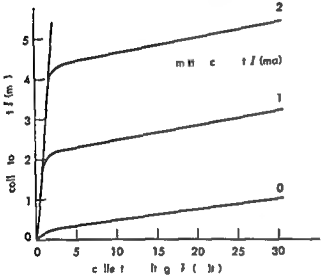
In th e sed e t n the e a br akd wn phe me t rel ti ly h gh ltage d e e th r t h at a al h g of th m n ty a rie s p g th ugh the h gh fi ld b r e eg n

[L P HU]

Point contact transistor

A t a t n wh h th em tte nd lle t c n t f met l po t t cts l ly p ed n th f e f a bl k f m c d t Th su l fig t w th both p t th m fac d ab ut 2 m l p t (e ll t tio) alth ugh g d de ha als b e m de with th p int pp t des f th n w le f sem nd t Th typ f tra st w th fi t tra t l k d ted The m t c mm n type u s n typ m c nd t m t l beryll um c ppe m tt r p t m te l a d ph ph b ll t p i t m t l l f b t the rf f th m c d t ef lly l pped nd t hed Th ha p po t m h ally embl d w th me p ing





Po t contact t a stor cutaway and charact ist cs

pres ure against the surface The collector point is electrically pulsed in the rever n bia direction with sufficient voltage and total energy to cau e electri cal breakdown The point of contact is heated nearly to the melting point of the emiconductor The pul e duration is a milli ec nd or les The re sult of this electric forming procedure is to in crea e the current multiplication fact r α of the collector point from omething much le s than unity to the order of 10 0 The injectio i efficiency γ of the point emitter i ab ut 0 3 and the transfer effi ciency i about 1 0 o that the o er all current gain α of the device is 3 0 *See* TRANSISTOR

The electrical forming proce s be ide increas ing α^* al o increa e the collector barrier leakage current I so that at a collector oltage of 10 volt a typical point contact de ice will draw 1 milliampere in the ab ence of em tter current This compare to 1 micr ampere f r a junction tran is tor under the same cond tion

Point contact transi tor can be made w th fre quency rang up to 100 megacycle and power rat ing of 200 milliwatt They can be u ed quite con veniently for o cillators and flip flops because their $\alpha > 1\,0$ cau e them to how a negative re t ance characteri tic when the ba e is u ed as an input They have not achieved widespread accept ance because of the variability of their characteri tics and becau e of their relatively hi h I

[LPHC]

Bibliography W Shockley *Electrons and Holes in Semiconductors* 1950

Poison

A sub tance which by chemical action and in low do age can kill or injure living organi ms Broadly defined poi on include chemical toxic for any living form microbes plants or animal For ex ample antibiotics like penicillin althou h nontoxic for mammals are poisons for bacteria In common usage the word is limited to ub tances toxic for man and mammals particularly where toxicity i a substance s major property of medical intere t Be cause of their di ersity in ori in chemi try and toxic action poi ons defy any simple clas ifica tion Almo t all chemical with reco nized phy io logical effects are toxid at sufficient do age The same compound may be considered a drug or a poi on depending on dosage effect or intended u e

Origin and chemistry Many poi on are of nat ural origin Some bacteria ecrete toxic proteins (for example botulinu diphtheria and tetanu toxins) among the most poisonous compounds known (*see* TOXIN BACTERIAL) Lower plants noto rious for poi onous properties are er ot (*Claviceps purpurea*) and a variety of toxic mu hrooms Ergot a fungal parasite of rye ha been the ource of nu merous epidemics of poi oning from the u e of contaminated rye flour The fungus contains many different alkaloid ome of which are al o u ef l drug Among the be t known toxic mu hroom are the fly agaric (*Amanita muscaria*) containing mus carine and the de troying angel (*Amanita phal lo des*) who e toxic agents are phalloidin and manitin *S e* MU HROOM

Higher plant which con titute the major natu ral ource of drugs contain a great variety of poi onous sub tance Many of the plant alkalo d do ible a drug or poi on dependin on d e The e include cura e quinine atropine me caline morphine nicotine cocaine picr toxin tr ch nine ly ergic acid and many tl er Some of the alkal id ere u ed in cla ical antiqu ity (com ne as the toxic agent of tl e extract of p tted hem l ck *Conium maculatum* drunk by Socrates) S me are f prehi toric antiquity (quinine and cu rare were u ed by Soutl American Indian l ef re the ad ent of European) a d me date fr m our earliest record of man (the opium p pp i be lieved to ha e l een cult ated in tl e Stone Age) *See* ATROPINE COCAINE MORPHINE QUININE

Po ons of animal rigin (enom) are imilarly di er e Toxic marine animal alone incl de exam ples of e e y pl ylum fr m Pr t zoa (din flagel lates) t Ch rdata (a number f fi l e) In ect and nake repre nt the l est kn wn enom u land animal l ut on land t o all phyla include

po so prod ing pecie Amo g mammalian e mples certai shrew with po n pr ducing li ry gland *See* DI OFLAGELLIDA

P so f l i g o gi ry n chemi al mplexity f m the toxi eleme t f r example th he y m tal to mplex ynth t c o m mol ules M t of the he y metals (g ld s l r mer ty ent lead) a po of l igl po te y in the fo m f th r l lle alt Str n id or b es e to i l gely le a f co o- e l al ti u anj y i e t o fo x mple somet mes e lt f tal pe l rat of tle ga tr t t l tr ct Ma y ther el m ntal b ta c are t xic t l w e nt ati n el n m ber ll um c dmium margan e ph pl a d zinc l g e l t may b a t c pat d th t any ch m lly r a t e el m t i likely to be tox c to m les t ents n l the b lk el me t n the body in th n c form in wh ch t ists n the body Na K Ca++ nd Cl f example a e r l t ly n t x c

The h m lly r ti e g es hydr gen ulfide h d oxya id chl i e b m and amm t a l ot e at l w c centr t both be ca e of th e r s e d b a of mor ful chemi l nt ract on with nzyme or ther ll t t A e mpl i the t x c act on f ya d i e p b bly expl ned by ts na ti a of it ch om o d *S* CYTOCHROME

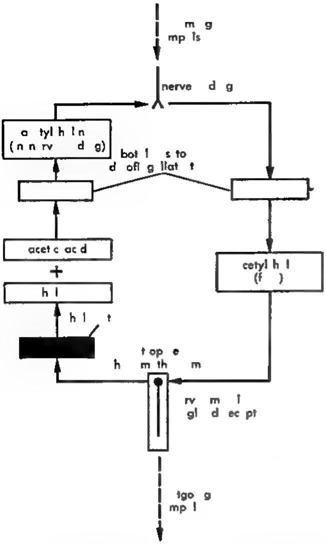
M r ga c s b ta ce f ynth t ag r i hly to d r p e e t may s u ce of l t l h z d M t o gan l ent ar more les t x t e g e t n h lat Etha l t a l t ely n u u e cept on in part be au e al ble e zymat t o han el it nt ma l n rm l m tab l p thw y al g wh ch t an t o d zed t u duct f m li to m m l metabol m h a t te M y th al h l h m th l m h m t x c Many f e t (f ex mple b n t tra hl r d tet chlo- oeth ne d d *th lene gly* l) n au se e h m l i j ry to th l e d th v e som tim f om r th r l w d g W th erta n po son f th p a high d g f a iat on n l d al pt b l ty ex t

Chemical correlations S p ep e t ll h m l l f m th l m t t e mpl lk l d and l p r s ge l h m l l t t n ha n d fi g lu f to ty H w ev l m ted t n hem l fe t r l t th t x c ct n M y of th hl i at d h d oca b fo mpl (b n tetr hl de) h m l t x ty f t h h a t nd k d eys A n mb f lkyl ph ph t s (d p pylfl o- ph phat t tr thylpy ph ph t a d rel t d compo d) ry pot t nh b t s f th n zym a tyl h l t e d p d t nt set f phy l g cal cha ges g f m th i c t t f th m A mb f t rt y m es l m t d (p a) loc l th t nd al h r m k d di l n n y t m t t Th d g t l gly o-

ide all repre ented by ster ds co d n ed with sugars and conta ning an additi nal la t ne ring hare many pharmac log cal p pertie n tal ly haracter t c eff cts on cardiac f inction which make th e d ig e rd ot in at l w nc ntra t n

Physiological actions The acti n of poi n i ge ally de cr l ed l y tl e pl i logi al or l io- chemi al change wh ch th ey produ e For m t p s a de cript e a unt c n l e gi en wh ch indi ates wh t rganic s tem (f r xampl h art kidn y l er bra n b ne marr w) appears t l e mo t rit cally in l ed and tr b te m t t e ri u ly di ord red l dy function r de th In man ca howev r gan effe ts re m ltiple or f nc ti nal d ra gement o ge e al ed that a cau e of death can ot be localiz d

Althoi gh a omp hen i e l t cannot be pr se ted here me ill trat on may l e gi en An oxi l ck of o ygen f r ell lar r pirat o can re ult fr m po on a ting at d ffe ent ite I h g n o th nhal d rro i e vap rs ma pro- d ce ma i fl d ng f tl lung with dema fl i d nd th s au e me han cal ffo at n C r n mo o id a t by b nding to hem globin with a mu h greater affi ty tha yge and pr d ce n xi by interfe n with oxygen tran po t Cyan de pre t ti s e re p rat at a term n l intra ellul r te l y p n ng it ch ome oxid e wh h at lyze th fi l tep f xyge i til zat n Ce tral nerv y t m dep with oma an l ult mat re pirat ry nd cul tory fa l re re ll from a l rge gr up f d g the g n l an e th t s (th chl fo m yclop pa ethyl e) the b bit te th p um alkalo d (m phine d nd el t d comp d) and le e la ly f m m ny othe p ns Live in jury w th j d (to c h pat i) a p minent es lt f m y po n cha t tically th chlo- t d hydr arb n l mental ph pl o u ce tai hea y m t l (en ant m y barium c p pe) a d l rge d e ty of gan mjo d K dn d ma e lt f m man t h m cals b t mm n ft p su t arbo t t a hlo- de m c lt d ethyl e gly l C ul n m t me fatal e a mm n re p t t p n by d e e a t b t are a p ti l ly ha t i t ff ct f t ychr n at o- *p n g t alkyl* ph phate t ca e a d ta n n ke v n m Am g th m d lly im p t t t x ag nt are th e that red e r ag t effe t v tr n m f th ner e mp il a s syn pt ju ct s r lly n the auto- n m n rv u y t m All s ch c mp u d ome t m s alled ut n m c ge ts a t o t mimi o t bl k th phy l al ff ts f th f th tw k own ne h m l tra m tte b t n of th m t b hes f a t e n ry tyl h li a d p phr n S ACETYLC IOLI E P s th t a t to e agg t th phy l g al ff t n mally p d d l y etyl h l le l d m and p l p ne Th t



Fg 1 Ac tylchol e cy l th to g t of many po o s Th t hol n terase po s s p event the kdown of acetyl h l e by act t g cho- l t a e (black) B t l us a d d flagellate t ns (g y) h der th synth o th el of ac tylcho l ne C ra a d at m ke th pt (h t hed g ay) l se t to th chem cal st mulus (Adapted f om Sc e t f c Am a 1959)

cholinestera es (neosti_gmine physo tigmine and the alkyl pho phate) have tl e same general phys iological effect although by a d ff rent mechani m The compounds low the heart lower blo d pre ure increa ecretion of fluid nto the re pira t ry tract and narrow the re pirato y pa age Toxic do es may pr duce death by uffocation or by failure of the circulation P i ons that prevent acetylchol ne from producing keletal mu cle con traction are curare and a numl er of related yn thetic compound i ed in ane the ia (succinylcho- line decamethonium) The drugs re ult in weak ne s of all voluntary mu cle and m y ca e death through paralysis of re piratory mu cles Exag geration of the normal effect of norepinephrine and ep nephrine (adrenergic drug) may produce dangerou ly high blood pre ure rapid heart a tion and ometime fatal di turbance of card c rhythm *See* EPINEPHRINE

Many normal functions (glandular ecreti n and contraction of voluntary and mooth mu cle) d pend on the cyclic relea e breakdown and re n the is of acetylcholine at the endin of cholinergic (acetylcholine ecretin_g) nerve The accompan ing illu tration indicates the different wa in which everal di tinct poi on may interfere with the normal operation of the acetylcholine cycle In the acetylcholine cycle an impul e reach ng a nerve ending liberate acetylcholine which t mu lates a receptor The receptor i freed for further impul es by the enzyme cholinestera e hich breaks down acetylcholine into acetic acid and cho- line The are resynthe ized by other enzyme into new acetylcholine

Mechanism of action More preci under tand ing of the mechani m of poi on requ re detailed knowledge of their action in chemical terms Inf r mation of this kind i a ailable for only a few com pound and then in only fragmentary detail Poi ons that inhibit acetylcholine tera e l a e toxic ac tions traceable to a ingle blocked enzyme reacti n hydrolysis of normally ecreted acetylcholine De tailed under tandin_g of the mechani m of chemi cal inhibition of choline tera e i not complete but allows me prediction of chemical tructure likely to act a inhibitor

Carbon monoxide toxicity i al o partly under stood in chemical term ince formation of carbox yhemo_globin a form incapable of oxygen tran port, is ufficient to explain the anoxic features of tox icity

Hea y metal poi onin_g in many ca e i thought to in ol e inhibition of enzymes by formation of metal mercaptides with enzyme ulfhydryl groups the un ub tituted form of which is nece ary for en zyme action Thi i a general reaction that may occur ith a variety of ulfhydryl containing en zyme in the l ody Specific u ceptible enzyme who e inhibition explains toxicity ha not yet been well d cumented

Metabol antagoni ts acti e a p i on functi n by competiti e blocking of normal metabolic reac tions (e ENZYME INHIBITION) S me antag n t may act d ectly enzyme inhil itor ther may be enzymatically altered to form deri ati hich are even more potent inhibit r at a later meta l olic tep An example of the latter i the l i n thetic i co poration of metal olite analo into mu h mo e complex molec le particularly tl e in corp t n into nucle c ac d of altered ri e or pyrimid ne l a es uch a 8 azagi anine and 5 l ro- mouracil o the incorp rati n into pr te n f al tered am no a id uch a p fluor phenylalan ne r 7 azatrypt phan

A well tudied example of l io yntl et c pr d c tion f a highly toxic metal lic analog aro e from studie of fl roacetate a t xic component of pl t of tl e ge *Dichapetalu* Fl i roacetate i enzymatically on erted to flu rocitrate through reacti n an l gou t th e n rmal tep lead ng fr m acet te to trate The fl ior itrate f rmed

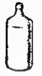
to icity rat ng	pract lly	l ghtly t	mod rat ly t	ry t	xtrem ly t	pert	p m ly t ic
mpl	gly w t g ph t l !	thyl lcoh l lysol t l p	m thyl (wood) l h l k th	t b p bo d ph l bo t t hl id	m ph b hl d f m ry	pot l m cy d h i trop	bot l t m k m
probabl leth l d mg kg	m th 15 000	5000 t 15 000	500 t 5000	50 t 500	5 t 50	l th 5	l th 0 5
probabl leth l dos for 70 kg (155 lb) m	 m th 1 qt	 1 pt—1 qt	 1 —1 pt	 1 t p—1	 7 drop — 1 t p	t t (l th d p)	

Fig 2 T ty t l f b t d g t d cy d th l t th dep ct d t m of p th f th p b bl f th l d M y d g f ll d t bl t Th c l w gg t d by M o N t th h ghly t t g D w g gg t th Gl R b rt E G l d H ld C H dg f l d se f w t wh k y th p m ph (Ad pt d f m S f Am 1959)

fr m fl et te p t t h b to of a ta a t at util zing n ym in the t ca b yl c d cy l nd th h b ti a pl the t x ty ffl c t t

Wh e p m ch m a e l t ely well u d tood t ha met me b p ble to empl y t lly sele t d t dote Th the l r fi t n f a c s ulfhyd yl p n l d t the nt d t n f the ffe t m t l p g nt d t d m re pt p p l (B t h a t l w t) Kn wl edge f th phy l gy of ti h l e te p so h p m tt d th f r t l phys l g I nt ni t f x i h l e g t mul t n u h a t p a d r On m r h m al b ec t t de f th zym t h m f ch l t h e l d t m re d ect t d te (p d ld x m m th d d d the m) f the t h l t e p n The nt d t t by r m ng the h bit f m the e zyme It h ld b ted th t f the g t m jo ty f po the mech m f t t n t w ll d t od s th l t d ex mpl b I nl a f w p n k w to t d tly by alte g zym f t Oth p p ba bly m h m n m m y l t w th l w ll d fi d lf l mp nt

Potency Th t gth p t y f p i t most f q tly m d by the l th l d p t n y be g ly p p t n l t l th l d e Alth gh k ll g d p e t f l e d p t f p t cy pp l m h m ll d e f g n po m p d t h g g m ln t m t g p te y l g t t p p l t n h l1 l d be f i h nt d d al t s pt b l ty Th l t h p b t een p t f p p l t k lled d d f po so som t mes h t f m t ym

m tr al igm d urve ep ent g tl e t gr t d o c m lat f rm f th l ll haped G u ian d t ib t n c rve Fr m t t ti lly t e ted d e p e d t the d k ll g 50% f the s mple p pul t ca be det m n d and t t lly d ig ated the MLD (m d m l th l do e) LD$_{50}$ Thi the mm n t mea u e f t p t cy alth ugh fo spe al p rp the lethal do e for th f a t n f the p pulat may al b d (for e mpl LD LD$_{90}$) The p ead f the d t ibut (f mple d e d ffer n b tw en LD nd LD) h ghly bl f d ff r nt po nd f u l g e tly i fl e d by th r l t h t g ty h m g e ty f th t t p p- lat S LETHAL DOSE 50

Health aspects The e n me t of ci il ed m b u d t t x c h m l d gs i d i t i l p od t f l p t de d m ny mm n h u h ld p d ts h s le n agent a d p t p d t A t d h p n g p t app e i bl p bl c h lth ha a d I 19 5 pp m t ly 8000 l w lo t f om p r t h m f l hem ls wh le the t mated numb f f t l id t w t l t 1 000 000 Of the f t l a e f a t p n g i 1955 pp x m t ly h lf we d l d h lf ac dental h m dal p o g r p s nt d l than 0 5% f the t t l

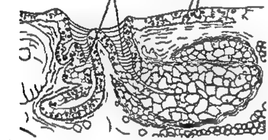
Th m lt pl at f t hem l ry d y l d 1953 t th t bl hm t f f m t t kn w P n C t l C nt wh h p d phy c a with me g y t l ph l m t m g t i ty d a t d t f mm p well f b nd n m d ch m l f m l t Th rv es w g atly t d by th p bl t 1957 f mpl t by M N Gl d th r f b and nam d

products with information as to ingredients and quantitative toxicity The authors of this book also propo ed a useful scale of toxicity here reproduced in modified form with examples of specific toxic classes *See* TOXICOLOGY [E AD]

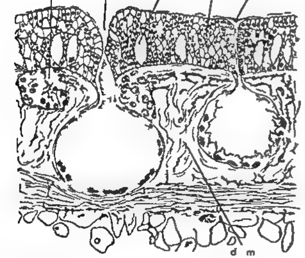
Bibliography L T Fairhall *Industrial Toxicology* 2d ed 1957 M N Gleason R E Gosselin and H C Hodge *Clinical Toxicology of Commercial Products* 1957 W S Spector *Handbook of Toxicology* vol 1 1956 W F Von Oettingen *Poisoning A Guide to Clinical Diagnosis and Treatment* 2d ed 1958

Poison gland

The specialized gland of certain fishes (illustration *a*) as well as the granular and some mucous glands of many aquatic and terrestrial Amphibia



( )



(b)

(a) Mult cellula po on gl d of catf sh (m d f d f m R d) (b) Amph b sk ge r l d (mod f d f m A B D wso a d G K N bl)

(illustration *b*) The poison glands of fishes are simple or slightly branched acinous structures which use the holocrine method of secreting a mucuslike ubstance The poi on glands of snake are modified oral or sali ary glands Amphibian gland are simple acinous holocrine with granular ecretion In some ca es the amphibian poi on glands produce mucus by a merocri e method of secretion The e glands function as protective devices *See* EPITHELIUM GLAND [O.E.N]

Poison ivy

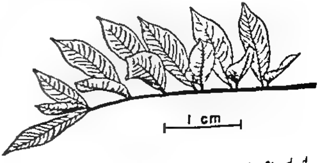
A general name applied to certain pecies of the genus *Rhus* in the sumac family (Anacardiaceae) *Rhus radicans* is the poison ivy of ea tern North America *Rhus diversiloba* is the poi on oak of California These plants are natives of North America Both cause ivy poisoning an annoying and often painful dermatitis

Leaf of po so ivy (L H Ba l y *The Sta d d Cyclopedia of Horticult re vol 3 M m ll n 1937*)

Rhus radicans the most wide spread species, is extremely variable It has a bushy or climbin habit, 3 foliolate leaves which are smooth and glo sy or hairy entire toothed or lobed Poi on ivy bears white fruit which differs from the nonpoisonous sumacs with their red fruits *See* HYPERSENSITIVITY SAPINDALES [P D S]

Poison sumac

This plant *Rhus vernix* is a member of the umac family (Anacardiaceae) It is an inhabitant of swamps ranging from Quebec to Minne ota and southward to Florida Louisiana and Texas It is a tall bush or small tree bearing pinnately compound leaves with 7–13 entire (without marginal teeth) leaflets and drooping axillary clusters of per i t ing white fruits Like poison ivy this plant is poisonous to touch causing in many per ons a e ere



Po on ma Rh (L H Ba l y *The St d d Cycl ped a f H t lt* 1 3 M m ll 1937)

i fl mmat n of the kin ≡ dermat tis The pres of wh te fru ts epa ates this pe ies from the p son um es with the red fru ts *See* HY PERSE ITIVITY SAPI DALES [P D S]

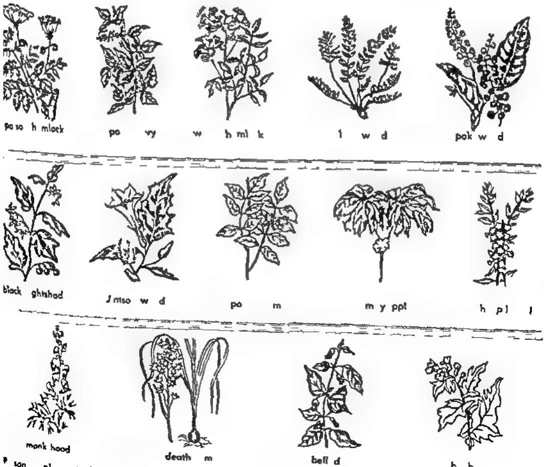
Poisonous plants

Alm t 400 p ie of asc la pl nt r pr ≡ ting 0 f m l h e b n li t d as p so ou plants ccu ng n the Unit d State Ab ut 100 of th e pec es au derm tit Am g thes a e uch c mm n pl ts a ≡ on y *Rhus r dic s p* son s m *Rh* ≡ *ix* and pe s l gl ss *E h m i lg* (POISON IVY POISON UMAC) Pl nts epr t g nea ly a c te f pec e p s- spi th ns o fr it h ng ha p awns h often c i j ry to im ls *See* FRUIT I VY) *STE I* (BOTANY) In dd t on t the e m y oth r p es mo app op i tely ata ed p n us pl t b au th ey ont n p pl wh h t ate pathol cal c nd n an mal

hxt e pecie k own t eau hyd yanic n g I this g p a e sp es of the ge a *gh m d P u* Wild h y *P unus se o* t s th mo t p iso u and w lted leaves of this pl nt co tain the greate t mo nt of the toxic glu de amygdal n which when broken down by e zyme a ti n pr duces the lethal l ydr cyan c acid Symptoms of p ning are taggering c n l o s difficult breathing bl ati ≡ and subse que t death u ually within an l o r after eat ng the lea e

In we tern N rth Ame c the two genera *Astragal s* and *Oxytropus* ontain al t 100 pe c e ma y f which are p onous In refe en to the cr z d reactions of the poi ned a m l th e plant ar c lle l l weed the w rd l c f Span I rigi mea ing crazy Tl ≡ animal l ses mu cul r c ntrol appetite flesh and ult matel d es Death camas any ne f a half do e spec s of the g nus *Zyg den s* an ther leth l t ch po on g plant f we te n N rth Ame ca The t ic pinc ple con sting of ne or m re alka l id ≡ ali ation nau ea miting tagger i g difficult bre thing and om time a state of coma wh ch may persi t for day f llowed l y death

W ter hemlock *Ci uta macul ta* and se e al oth r spec es of this genus conta a re l ke sub- tanc cicut xin found hiefly i the roots o root



P son pl (Ad pt d f m m t l W bst N I t I D I y S d Ed t py ght 1934 1939 1945 1950 1953 1954 1957 1959 by G a d C M m C)

stocks which is a lethal poison *See* ROOT (BOTANY) The symptoms in man and animals are similar nausea vomiting difficult breathing and violent convulsions ending in death caused by respiratory failure Poison hemlock *Conium maculatum* contains in its fruits and leaves a volatile alkaloid coniine which causes a gradual lessening of muscular power a rapid feeble pulse and gradual lung paralysis resulting in death *See* LEAF (BOTANY) Pokeweed *Phytolacca americana* has a poisonous root containing a toxic alkaloid and a glucoside which resembles a saponin The seeds apparently contain these same poisons *See* SEED (BOTANY) Symptoms of poisoning are vomiting purging spasms and sometimes convulsions which lead to ultimate death caused by paralysis of the respiratory organs

Plants containing the toxic alkaloids hyoscyamine and hyoscine are henbane *Hyoscyamus niger* belladonna *Atropa belladonna* jimson weed *Datura stramonium* and matrimony vine *Lycium halimifolium* Symptoms of poisoning are headache dizziness nausea great thirst failure of vision and in the worst cases mania convulsions and death In this same family are several species of the genus *Solanum* including European bittersweet *S dulcomara* and black nightshade *S nigrum* which contain the alkaloidal glucoside solanine Solanine poisoning in its commonest form produces symptoms of narcosis and paralysis In gastric poisoning it causes salivation vomiting bloating and diarrhea

Certain species of monkshood *Aconitum* contain the alkaloids aconitine and aconine in all part of the plant but particularly in the roots and seeds These toxic principles cause muscular weakness difficult breathing weak pulse and bloating Poisoned horses and sheep often recover A number of species of larkspur *Delphinium* contain several toxic alkaloids which cause animals to lose appetite to stagger and in severe cases to fall and lie with legs rigidly extended Mayapple *Podophyllum peltatum* contains a bitter e inou t xic substance podophyllin but because of the bitter taste these plants are seldom eaten in amounts that are harmful to stock

Sheep laurel *Kalmia angustifolia* and other species of this genus contain the toxic principle andromedotoxin which poisons sheep goats horses and cattle It causes salivation increased nasal secretions emesis with convulsions a d ul e quently paralysis of the limbs Animals may remain ill for 2 or more days and then recover

Oleander *Nerium oleander* introduced i tl outhern United States as an ornamental shrub contains two glucosides having properties similar to those of digitalis glucosides Sheep goats horses cattle and poultry have been poisoned by eating the leaves Symptoms of poisoning are nausea vomiting colic vertigo drowsiness low g of pulse irregular heart action bloody diarrhea unconsciousness respiratory paralysis and finally death

Various grasses including rye barley and occasionally wheat sometimes become infected with a fungus *Claviceps purpurea* (*see* FUNGI) In the heads of such grasses whole grain are replaced by dark hard cylindrical bodies called ergots, which eventually function in reproduction of the fungus Ergots are poisonous to stock and if permitted to eat infected plants either in pasture or in hay the animals develop a diseased condition becoming emaciated and often covered with sores In the worst cases portions of their tail or ear may be sloughed off In females abortion may occur [P D]

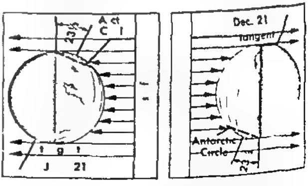
Bibliography W C Muenscher *Poisonous Plants of the United States* 2d ed 1951

Polar meteorology

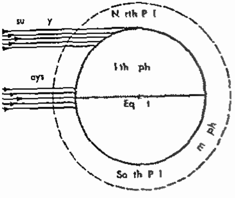
The application of meteorological principles to a study of atmospheric condition in the earth high latitude or polar cap region n rthern and uthern The e zones develop distinctive atmospheric character basically because of the obliquity of un rays and the alternation of long periods of darkness and daylight (*see* GEOGRAPHY MATHEMATICAL) Although polar radiation or its absence gives to the polar atmosphere its strongly contrasting winters and summers other phenomena exert important influence These include elevation the nature of the earth s surface (oil water thin no thick ice) the size of continents and ocean and their location with respect to circulation pattern

Winter During dark low un or winter es on the absence of the sun permit cooling of the no surface and overlying atmosphere The earth surface because it is essentially a gray r black b dy radiator cools more rapidly than the atmosphere This causes the characteristic polar temperature inversion or temperature increase with height. In a sunless cloudless atmosphere the extent of temperature inversion depends on the relative magnitude of compensating nonradiative heat fluxes — principally turbulent transfer of heat in the air and heat conduction in the snow

Surface temperature Rapid changes as well as extremes are characteristic At the South Pole on



F g 1 Th a g l l t o h p b tw e th d ect on of th n gy o d th rth s s rf c ha g d g th y N t th f of w te p ed m ant da k s a ag t th s mm r s lo g hours f d yl ght rth and th n p l g o s



! Th blq y A h cte t f p l d l l e gy t th rth f th ert l y B b t gy p d g rf d b t p th gh o l y f b b g d fi t p tm ph h d h t gy

'll 1957 a urf t mper t e of −101.5 F observed w th le kies o-mph wi d l ttl pe t g h t d cti b ce of s light a e o of 60 n 2500 ft Howe wh tm l d l ye m d in t d w w d rad arm d th u f e 16 i 3 h s th n rthe n p l gio l w st w t tem at less dent w th the p le When e bl he t co d t n f m bel w i a il t mp n t f the r d t e l a n th ct B n s f c t mp t es d n t f ll t l w l e b rved o adj t c t t e l we t t mpe t the N the n H mi here a b erved t h m e tal l t kh k (−90 F) n rth ste n S b ch f th r n rth the Ar t c O ea Ba n the t t mp t re th p ck s ly −(2 F d the th ke Fletch I I l nd l ghtly e −65 F

Co t t l a d m i e e d ff tempera e eg me. The l m h f t mp t f co t tal p l tm phe e h sh p m n m lly e m th ft th w ter l t ce t t th atm ph th A tic n d th C ad A h p l g h fi t w m um m f l m th d t d g h h th m y b eve l m m ma d n m S p i ngl n gh these fl t w te n m a l f d i th d dedly nm m t t s f G f d and A ta t Ap p tl mp t g d t f w me f m th n by c esp bl d th p- pea t ffect the m lle t t l h A r t d G la d m h m d ly tha th n th n t f th l g t nt f A d N rth Am a

Wa p d p p t t Low atm ph t mpe t dec w t p t th t P rp t t m a a d f g f eq t H w h th e i n w t tifi l el l p w t p at mpe t b l w −90 F h ll w f g f m t ery t l f m

At the S th P le le th n 3 i of water eq a le t cc mulates in one ye l t the lack of e p t r r noff enables the b ld up of ice thou sa ds of feet thick e th ye rs

Upper a p tte s Abo e the hallow s rfa e inve sion a temp at decrea w th he ght u t l the t p p t e hed If the lower t to- ph e is wa m −60 to −75 F th the trop pau e i e i q t sharp B t if the t t phe e is c ld −90 to −110 F the trop pa may b me ill defined Thi disappearance of th w ter tr po- p wa th ght t l e characteri t ly f the A tarcti tm phe e but it now b rved when cold int e cy l es a pre e t i the Arc t t at sphe e High g radio ndes s m time h w what appear t be ther trop pa ne 18 km

I both p l r strat ph es a t g horiz tal t mperatur gr d ent u ally extend acr s the tw l ght z ne wh h in tur se a str ng w nd jet, called the polar ght jet In the Arctic the deg ne ti n f th jet f m a qua nal fl w t a meande eddy flow ften s bef re ret rn of the n and m y re lt from th l ge t nental ce ni ntra t in the N thern H m phe This ddying m tio whi h t c at d w th m ked w rt i g al edi t b tes th ne cr t d i the l wer str t sphe e by the acti f sol ultr let diat o tmo ph ric ygen I contr t th Anta ti trato pheri jet d t ch ge t al char ter u d go ifi t w mi ntil the r tur f th un

Summer The r t rn f th n y t pol r g prof ndly cha ge the t mp tur cl ud a d wi d g me Th m t r p d heat g r m tl l w t at ph e wh the la lt l t r diat n s st o gly bsorbed by o e In A ta t ca the t at ph c h ti g i s r pid th t tw m ths the w nte p tt f t g l w d t mp at d ea e s e ed C e- q ently the te p l ycl e w th t l t mp t s r −110 F fte b omes a w k a t cy lon w th ce t l t mpe at near −40 F

Be u e f the h gh lbed fle ti ty f w t l r d at (80-90% f th i c d t d t) the amo t f b bed di ti m ll b t g d ally th t m w k d bl t te th su f i e t I onti tal whe th sn w m tle s th the n w m lt *nd exp* the b gr u d wh ch th b p a t lly ll f th d t d t d p dly wa m to temp atur l f m ddl l t t d s l th Ar t pa k m lts d lly (a m h s 3 f et) p n w t l d pp d the alb d d cr to alm t 50% A t c temper t e rem 32 F but th a ed pply f w t p f m e p t ges f rm t f l w st at l d a d f I A t t a ay f m p d mou t n k d th da k f th s ery l ttl w m lt e p t He lb do m h gh nd w k rf m y le f u d n mm F g d t t l d a m

frequent in coastal areas where moist maritime air moves in and is cooled from below.

Influences of polar air masses In winter and summer polar air masses play an important role in the general circulation of the atmosphere. They move equatorward into and through middle latitudes in sporadic impulses to help equalize the irregular distribution of solar heating over the earth. These outwardly moving polar air masses contribute greatly to the diversity of air turbulence and storms which mark the weather and climate of many parts of the middle latitudes. *See* AIR MASS; FRONT; STORM. [H.WE.]

Bibliography. T. F. Malone (ed.), *Compendium of Meteorology*, 1951; M. P. van Rooy (ed.), *Meteorology of the Antarctic*, 1957.

Polar molecule

A molecule possessing a permanent electric dipole moment. Molecules containing atoms of more than one element are polar except where forbidden by symmetry; molecules formed from atoms of a single element are nonpolar (except ozone). *See* DIPOLE MOMENT.

The dipole moments of polar molecules result in stronger intermolecular attraction, increased viscosities, higher melting and boiling points, and greater solubility in polar solvents in comparison with nonpolar molecules.

The electrical response of polar molecules depends in part on their partial alignment in an electric field, the alignment being opposed by thermal agitation forces. This orientation polarization is strongly temperature dependent in contrast to the induced polarization of nonpolar molecules. *See* DIELECTRIC CONSTANT; FERROELECTRICS; MOLECULAR STRUCTURE AND SPECTRA; POLARIZATION (DIELECTRICS). [R.D.W.]

Polar navigation

The complex of navigational techniques modified from those used in other areas to suit the distinctive regional character of polar areas. Although polar navigation has become routine to a rising number of navigators operating in and through such high-latitude parts of the world, their success continues to be based on a sound grasp of the regional differences and the developing adaptations of navigational principles and aids to suit these peculiar area needs. This article therefore singles out salient physical differences from those of other areas which demand navigational modifications and relates them to the best known special techniques and applications.

Coordinates, directions, and charts In polar regions the meridians radiate outward from the poles and parallels are concentric circles. Thus the rectangular coordinates familiar to the navigator accustomed to using the Mercator projection are replaced by polar coordinates. A rhumb line is of little use in high latitudes. The usual significance of direction decreases as latitude increases, disappearing at the poles where all directions are south (or north).

Polar navigational grid. For navigational purposes it is convenient to restore rectangular coordinates. This is done by placing a series of parallel lines on the chart and letting them represent fictitious meridians. This is called a navigational grid. Generally these lines are parallel to the Greenwich meridian and grid north is taken as north along this meridian as shown in Fig. 1. In this way grid and true directions near the poles are interconverted by the addition or subtraction of longitude. Variation of the compass (magnetic declination) is replaced by grid variation or grivation, which is the angle between a magnetic meridian and a grid meridian. Thus grid and magnetic directions are interconverted by the addition or subtraction of grid variation.

Selection of chart projection. As latitude increases, the Mercator chart so familiar to the marine navigator of lower latitude becomes of decreased utility. In subpolar regions—roughly in the area between the 60 and 70° parallels of latitude—the Lambert conformal projection is used increasingly for nautical charts. In higher latitudes both nautical and aeronautical charts are generally on a polar projection. The polar stereographic and transverse Mercator projections are used most commonly, but the modified Lambert conformal (Ney's), polar gnomonic, and polar azimuthal equidistant projections are also used. *See* MAP PROJECTIONS.

Light conditions At the poles the day and year become synonymous as regards the proportion of daylight to darkness. The duration of twilight is lengthened proportionately, lasting several weeks. About 32 hours elapse from the time the lower limb of the sun touches the horizon until the

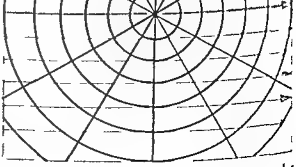


Fig. 1. A polar stereographic graticule with a polar grid overprint.

pe limb d appears at un et during which t me e ntra els l 3t ne (480) around the h ri on he pe od of eral d ys that occurs each spring d ut m hen the un i b l w the h r zon b t n cl se to t for th er cele tial bod e to b ible t t l t me f r n igation b cau e f the reat d p nde ce upon cele t al bod e for both c it d d rect o d te m at on

Celestial sphere and time patterns The d urnal n to of l tial bod s e sent lly h ri ntal Half f the cele t al sph e is always ible t each pole a d the the half i alw ys l low the horizon T m lo es its u ual gnifica ce i g n th re all t me nes om t gether The t me of t y zone w ld be abo t equally ati fact ry It is comm n p ct ce t k ep Gre nwi h mea t me

Meteorological factors Temper tures re gen r lly l w b t ot as low as m ht be upp e l It is tru th t th c ld t atmo pher tempe tures re e ded h e b en th Ant ct c ntin nt but temp t at the No th Pole are ne e as l w a som ded in Yell t ne N ti l Park Al tho gh *few pl c* in Ant t ca eve get ab e f ezing much of th Ar t d s reg la ly ea h mmer A temp tu of 100 F ha been rec ded n th A t C le

The polar i lat vely dry b t be ause of the l w p eva l n t mpe t r s *fog* and cl ud a mmon Vi b l ty may l be l m ted by blowing sn w In m t p t of th pola e n prec pit t l ght th t th area re met mes cl sed de erts N e th l s *o er* mu h f b th polar a the e do *ot completely* m lt d g the s mm d large q ant t es f ic a e l ft bo h o th l nd d i the s Whe th re is n f g the atmosphe e c pt on lly le In the l a c ld m f p l r eg s ds t l gr t d ta es It s t un l t h a the l k of d g 10 m les w y

The t nge t surf ce w nds in the world p bably n t ed erta n g f A tar tica, h e speed f m e th n 00 kn ts a e t n u l O r the A ct c O a h weve tr ng ind t nco nter d e ept n s m regions l d.

Th e d t ns d scr bed a e pr marily e p n bl f th d ffe n b twe n n g t n n p lar r g nd el e h r Th e is well defined l f d m t n betw n pola g n and s b p l g n n r th u t r al g em t as f th d ff t n f p l eg Fo the p rp e f th d scu h wev the p all l f lat t d 0 a en ntly b u d g n r l di d ng l ne P la g d n gat o s n lly l m t d t th f t d p lew d f th s pa allel

Piloting hazards P l ti g p l g n st gly affected by th b n e f a y gr at n m ber f d t n n t n Al natu l l ndm ks m y not be t th ha t r m y be d ffi ult t d t f The app a nce f m l ndm rks h ges m kedly d d ff nt e c nd t o Wh s w both the la d a l a w d

foot attached to the hore and extending f r miles to e w rd even the hore line is d ff cult to locate Adja ent island omet mes merge together as the st a ts between them fill up c mpletely with ice Along a rugged coa t u h as *that of much* of Gre nland n w covered h adlands may look al k

Unreliability of charts Cha ts f polar regions are le s reliable th n th e of other reg n l e c u relati ely l ttl surve ing has l een d ne in the p lar rea Atte pts to fix the po iti n f a craft can be d couraging when the a ou landma ks used re not charted n *co rect po it n relative to* e ch other Mari n na igat rs m times plot p i tion elati e to land known t be shown in the w ng place rather th an in the co ect geographi al p s t n becau e t is th la d and its attendant hoals that on titute danger to their s l

Becau e elat ely few o ndi g a e h *wn on* charts h p ente ng ha b r *often* end mall bo ts ahe d to det rmi e th e d pth of water a ail able The polar marin na ig tor finds a kn wledge of geol y eful in pred cti g safe a a nd tho e n which rock and h als m ight b enc untered Ice con ent ati ns a d m ement may al be an indi ation of lati e depth f w ter

Limitations of electronic applications Ele t m aid a t b ndant n p l r regions Lor n co e ge xte d to m parts f th Arct Radar us ful b t e pe te ce i inte p et ti n f the pe n pol r e io s e ntial f r rel al le re sults Th i pa ti ularly true in a raft where th relat v app ara e of w t d l d a e f ten e s in w te and summe H mm ked ice pre t a d ffe e t appe ranc f m unl oken e *A rad d re ti n fi der i* eful when rad ig al a a a l ble Ex ept al n the n rthe n e st *of th U S S R* f w d be are a lal le Th us *of* el ctro ic in p lar reg n i fu th r re ted by magn t st ms which re particularly s e e th auro al n

Difficulties of dead reckoning Rel able de d k n ng d pend upo the lab lity f ac ur te m a u me t f d e t o a d d tance (or speed) S me diffic lt es re e *ou te* d i meeti g th se requ r m nts n p la reg

C mp s l m tat n D r ction m ed l rg ly by a mpa The c mpa es n mmon u e a the m g t i wh h th d re t e le ri nt tt mpts t l gn t elf with the h ontal m ent f th a th s magnet c f ld nd the th k ng gy m m wh h the d re t l ment tt mpt t lign t lf w th th a th s axis f rota t on Th m gnet c mpa be omes unrel able in th v ty of th magn ti p l s f th n th and the th k g gyr mpa s bec m s u l ble n th ty f th ge g apl cal p le f the arth The m g et c and geograph cal pole both h gh l t tude nd the ar n wh l the mpa r o s re la ge nd s mewh t e at rl p l the fr q e t ch ck nd om p t re ne ded Th d ct l gyro mpass w lely sed n a aft p r t g i pol r re-

frequent in coastal areas where moist maritime air moves in and is cooled from below.

Influences of polar air masses. In winter and summer polar air masses play an important role in the general circulation of the atmosphere. They move equatorward into and through middle latitudes in sporadic impulses to help equalize the irregular distribution of solar heating over the earth. These outwardly moving polar air masses contribute greatly to the diversity of air turbulence and storms which mark the weather and climate of many parts of the middle latitudes. See AIR MASS; FRONT; STORM. [H. WE.]

Bibliography. T. F. Malone (ed.), *Compendium of Meteorology*, 1951; M. P. van Rooy (ed.), *Meteorology of the Antarctic*, 1957.

Polar molecule

A molecule possessing a permanent electric dipole moment. Molecules containing atoms of more than one element are polar except where forbidden by symmetry; molecules formed from atoms of a single element are nonpolar (except ozone). See DIPOLE MOMENT.

The dipole moments of polar molecules result in stronger intermolecular attraction, increased viscosities, higher melting and boiling points, and greater solubility in polar solvents in comparison with nonpolar molecules.

The electrical response of polar molecules depends in part on their partial alignment in an electric field, the alignment being opposed by thermal agitation forces. This orientation polarization is strongly temperature dependent, in contrast to the induced polarization of nonpolar molecules. See DIELECTRIC CONSTANT; FERROELECTRICS; MOLECULAR STRUCTURE AND SPECTRA; POLARIZATION (DIELECTRICS). [R. D. W.]

Polar navigation

The complex of navigational techniques modified from those used in other areas to suit the distinctive regional character of polar areas. Although polar navigation has become routine to a rising number of navigators operating in and through such high latitude parts of the world, their success continues to be based on a sound grasp of the regional differences and the developing adaptations of navigational principles and aids to suit these peculiar area needs. This article therefore singles out salient physical differences from those of other areas which demand navigational modifications and relates them to the best known special techniques and applications.

Coordinates, directions, and charts. In polar regions the meridians radiate outward from the poles, and parallels are concentric circles. Thus the rectangular coordinates familiar to the navigator accustomed to using the Mercator projection are replaced by polar coordinates. A rhumb line is of little use in high latitudes. The usual significance of direction decreases as latitude increases, disappearing at the poles, where all directions are south (or north).

Polar navigational grid. For navigational purposes it is convenient to restore rectangular coordinates. This is done by placing a series of parallel lines on the chart and letting them represent fictitious meridians. This is called a navigational grid. Generally these lines are parallel to the Greenwich meridian, and grid north is taken as north along this meridian, as shown in Fig. 1. In this way grid and true directions near the poles are interconverted by the addition or subtraction of longitude. Variation of the compass (magnetic declination) is replaced by grid variation or grivation, which is the angle between a magnetic meridian and a grid meridian. Thus grid and magnetic directions are interconverted by the addition or subtraction of grid variation.

Selection of chart projection. As latitude increases, the Mercator chart so familiar to the marine navigator of lower latitudes becomes of decreased utility. In subpolar regions—roughly in the area between the 60 and 70° parallels of latitude—the Lambert conformal projection is used increasingly for nautical charts. In higher latitudes both nautical and aeronautical charts are generally on a polar projection. The polar stereographic and transverse Mercator projections are used most commonly, but the modified Lambert conformal (Ney), polar gnomonic, and polar azimuthal equidistant projections are also used. See MAP PROJECTIONS.

Light conditions. At the poles the day and year become synonymous as regards the proportion of daylight to darkness. The duration of twilight is lengthened proportionately, lasting several weeks. About 3? hours elapse from the time the lower limb of the sun touches the horizon until the

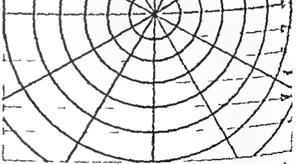


Fig. 1. A polar stereographic graticule with a polar grid overprint.

t p the es el cru h it It is ually cons dered ett r t keep m in n the gen ral d rection d red than t isk mpl t topp e with p s ibl lam ge by sta e a tly the des ed c ur e All th pl a l k l det led inf rmat n on cu t ath l ttle pp rtunity to acqu e it mak m n e de d recko ng diffi lt p l r reg ns

Celest al n t at o s f great imp t n e in pola reg fte prov d th nly mea of determ i p t n urat ly r e tabl h n d ectu al fer e

Celestial navigation problems In w It the use of a ta t t th m as t i th f t t des Abo d h p marine xta t a be d he c l tal b d es nd h h iz ar l th a l able oc rr n e mo e f q e t n mo t cea a s at l lat t d s Sm the pack mooth the se re ult g e y l ttle ll g or p t h of a h p perat ng in t e ome mar ne na gat s ha e f d an art fici l ho z n e nt of the type car ed a r aft ful. If the a cel at on e r too gr t abo rd h p bserv t on f m a n arby w ke m y be pos ble

Wh pe t l w r latit de na t g lly a d h erv tion of b d e s th ho zon bec f the ert ty f the ref act rrect n the e In pol eg on e n tho gl f a t m e ert n a g t r oft n h h the q n e the n m y be the only bod l ble f r eve al e k a d t ema l e to the ho zo Unde the o d t n th t b erves th n and mak s th m t f th r l m t h h s usu lly with at fact y res lt

Du g th pola mm r the ft n the nl lest l b dy a labl Th mo n ab e th b ri half the t m but s a fa bl p t n elat t th s du ng l t v ly few day a h m th Wh nly n b dy a labl t bserved at freq nt t rval p hat h ly d series f ru n fix pl tted

T m g f cel t l b r t l a t al pol re s th n l w l t t de b e p ra e t m t f th b d e s n a ly h r tal A tel t ely l g erro n l t d th ffect f err n t m rel t el m ll n l a a h e th m d a e l e t g th r s ght red ct pol r gi n s n t att d d b l p bl m Th m m th l s comm t l w l t t udes a d p l gm S mpl fied t bl m ght b p pa d b r they g all a d d f f m l r method S CELESTIAL NAVIGATION NAVIGATION PHOTOG

[A B S]

B ll s phy N B d t h Am P ct I l U S Na y Hyd g ph Off HO 9 1958 U S N vy Hyd g aph Offic At N g n HO 1C 19 5

Polar triangle

Th pol f a g t le n a ph e th p t f th phes wh p p d l r to th pl f th g t l t t nt ut th sph e T btain the polar t iangle f a spher al tr an le ABC (see TRIGONOMETRY SPHERICAL) onstr ct on ts phe e three gr t cir l ha ng re pecti p le A B and C Tw g eat cle ne ha n B and the ther C a p les nter t in t o poi t n t p it hem p l e e defi ed by the great rcle thro gh BC Denote l A tl poi t l t g on the same hemi ph e a A Lo ate B a d C by a l ke p oceedure The spl r al t iangle A B C s the p lar tria le of ABC In ge metry it i l wn that if ne pl erical tr angle t the polar of a e nd then the eco d i the p lar of the fi t Al if the tri ngl ar lett red in the conve t nal way then

$$A + a' = B + b' = C + c' = A' + a = B' + b = C' + c = 180$$

[L M K]

Polar wandering

The large cale cular mo ement of the terr tr al pole the fact f t h m eme t th igh l a d on rt e dence emains p culati Such m ti n is n ddit on to th mall al 14-m nth cycl ari t on (Cha dle mot on) Se GEODESY

Co id l le e t fic e id e p i t t v rd a relat n hip l etween po sible p l r mig t n and m t of the a th s ub r tal mantle with re spe t t the a th s hea o e If th earth s ig d shell or t v r bl cks wer to gl de on the m v ng m te ial l e ath th l ll w ld yield a d djust t ha g in the di r n of the p la a is

S e t fi d l a l e n an mated r th the ry of w tw d d ift of the N w W ld onti nent relat on t th Old W ld nt nt in trod ced by A Weg r n th 19 0 (al ce bas form t e SUBMARINE TOPOGRAPHY) M y ent t n w f el that th rate f u h d ft mu t b m nyt me m lle th as t m d by W ge e S m b l that t l m t p ed f t th t th Atl nt O an bas w ll bec me b d —wh th r fr we twa d drift of th N w Wo ld c t n nt f m the Old W ld ntine ts m a twa d f om both m ing a twa d but at a hi h r r t tward f r the Old W rld t ent T ma v th l t e ms m t l k ly nd fits theo e f adju tme t t t t rnal c n t on m m nt d t h ft in polar ax

Oth d t c ntr bute re or l di tly t the ept f p l r w nd ng. Vertic l and h z tal h ft t n nt l and o ean block n b me cum t nc n t o ly n dj t m nt to l its pol r s h t al tribut r f th h ft n th The polar fl ght theo r of e tr f al f te d ng t bri g th ntinent l sh eld r w d the Equ t appear to l ck ffi nt f t e al h ft g The f r te n l m m t ho e d ll w r a nable e pl n ti ns f r gr w n d g f m e rl e n d n e i p t n b tw en magn ti and g o g ph p l R l t d f rm ti n in th mate ial b tw

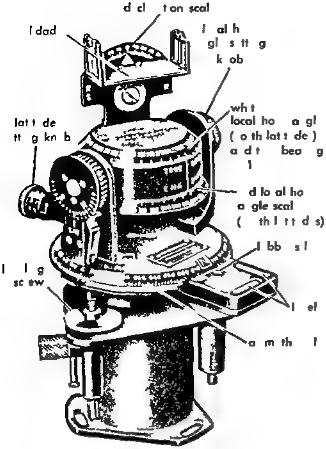


Fig 2 An astrocompass

gions but is not in general use aboard ship *See* Dead reckoning

Celestial determination of direction Direction can be determined by means of celestial bodies but this is usually an instantaneous indication used to check the compasses unless a device equipped with a clock mechanism is used to provide more continuous information Several types of devices have been developed to facilitate the use of celestial bodies for determination of direction The oldest is the sun compass which utilizes the shadow of a shadow pin or gnomon and a suitable dial This of course will not operate unless the sun is visible A sky compass indicates direction of the sun by means of polarized light in the sky when the sun is near the horizon even though it may be below the horizon or otherwise obscured This device may offer the only means of determining direction during the brighter part of the long polar twilight A Canadian version is called a twilight compass because of the principal period of its use An astrocompass shown in Fig 2 can be set for the coordinates of any celestial body and the latitude of the observer and then gives an indication of azimuth true north and heading

Distance or speed problems Such measurement in polar regions presents no problems in aircraft When ships operate in ice however the sensing element in the water may be adversely affected or damaged by the ice A method of determining speed or distance that has proved successful has been to track an iceberg or other prominent feature either visually or by radar If the feature is stationary as a grounded iceberg the result is speed or distance over the ground

At best dead reckoning is difficult aboard a ship operating in the ice not only because of the difficulty encountered in measuring course and speed but also because neither of these may be constant for very long Land ice which flows down to the sea and breaks off in the form of icebergs or ice islands is not usually a problem and may even prove beneficial Its use as an aid in the determination of speed has been mentioned Individual pieces are usually so large they move with deep-water currents often in a direction differing from that of the sea ice which moves mainly in the direction the wind blows Thus an iceberg might clear a path in the desired direction of motion One precaution is essential however It is dangerous to approach close to an iceberg both because of possible underwater rams which might extend out for some distance from the berg and also because it is not uncommon for an iceberg to acquire unstable equilibrium because of uneven melting and capsize

Ice formed at sea called sea ice is seldom an unbroken sheet over any very large area The unequal pressure exerted by tides currents and and temperature changes produce stresses that break the ice and move different parts of it relative to each other producing leads long cracks that have opened wide enough to permit passage of a ship polynyi large areas other than leads relatively free from ice or pressure ridges ridges of ice piled up where two floes have come together under pressure

A large field of floating pieces of ice which have drifted together is called the pack If this is relatively loose as shown in Fig 3 a ship skillfully handled can negotiate it If it is packed tightly under pressure however it is best avoided

Successful negotiation of pack ice is the result of working with not against the pack seeking out weak spots ramming when appropriate and retreating at other times taking advantage of leads and polynyi and avoiding heavy pressure that might

Fig 3 Pack ice

ed in b ochem cal esearch to identify the mo- lar nfiguratio s

Optical r tat ry d spe s n is th mea u ement the pec fi r t t n as a fun t on of wavel ngth mpl h th s the sod um lamp is epla d by m och m to and o re of e t n us radia on. A photocell i c it is b tituted fo the eye a d tect r In th way th p ific rotat on m y e det rm ed in the ult a i let o nea i frared w ll as in the bl region of the spectrum

The i f rm t n obta d l y pt al otat ry d n ha h w that m n changes onfig t n of mole le ha e a m rk d ff t n ts l persi n p rt By ng the pr perties f ompo ds f known onfigurat n it h s been po bl to dete mi th ab l te o fi u at n of ma y ther mole ules and t id ntify ar ous i o- n r T date m t of th appl cat ns ha b en t st roid gars nd othe n t ral ır du t S OPTIC L METHO S OF CHEMICAL ANALYSIS POLAR IZED LIGHT ROTATORY DISPERSION [R F G]

Polaris

Alpha U e Mi n th No th Sta o p le tar P l r i located pp oximately 1 of n f m th n rth cel t l p le th p int where the Earth s ol r t t on now p ces the elest l sph re T bright ta s t the nd f th bowl f the B g D ppe point towa d Pol

P la i h h l m ty t r f sp ct al t pe l te F It e f th b l te t epheid riabl b t typ cal h i g the mall l ght ang f o ly 0 l m g tude Th per d 4 d ys the lu min ty 3000 time that f the S n d st ce 200 par e P la ha a f int ma eq e e c m p n n Se STA [J L G]

Polarity (electricity)

A t rm wh h f r t the d gnat of p t e a d n gat e term ls i a ele tr rc t ca y g ent. Th ch ce f p t e ha ge nd th ebv f p it e p te ti l p r ly b t ry on wh h had b m de l g b fo e the d co ry f th elect n It is now k wn th t th p mary u e t r in mo t t l me t a ele t wh h po es ti h g

Fo a e t of l t m ti f c h a a bat t ry a g t th po t e t m al i b n tion th ne t wh h el ct n nt f m the ext r l t th neg t e t min l the f m wh h th y l F r a p l m nt h a n mmet or a e t r the p st e te m n l th e th gh wh ch th le t s le th eleme t th g ts t m nal th n th gh which they nt fr m th e t Th p t nt l f the po t term l f ny element by d fi t g y lue tha th t f th n g t v t rm n l In ll c se th n t al rrent flo th pp t d ect t the le tr

I th f alt rn t ng c r t th t rm p l r t m le u ed n d ffe t Us ll n m m l t l g m t ed t z po-tential while the ot er is alter ately al o e and be low ground In me electr cal appliance it makes a d fference which s de connected t the h t lead Tu ning th plı g a ound in tl e wall o ket to l t in the best oper ti n f a partic l r de ice i often referred to as ers ng the pol rity [J W ST]

Polarization (dielectrics)

A ect r qua tity repre ent ng the electric dipole m ment per it olum of a d ele tric m terial S e DIELECTRIC DIPOLE MOMENT

The polar zat on P i related to the macro copic electr c p ram te s by the quatio s

$$P = \frac{D - \epsilon_0 E}{\gamma} = \frac{\epsilon_0(\kappa - 1)E}{\gamma} = \chi\epsilon_0 E$$

where D is the elect ic d pla ement E is th elec tri field strength i the p rm iti ity of acuum is the di lectri con tant χ i the electr c u cep- tib l ty nd γ is a geometrical fact In cgs lec t o tat u ts = 1 a d γ = 4π ϵ_0 = 8 854 × 10 fa d/m and γ = 1 rat alized mks un t Th e d men s f p l ati n are tatcoul mb p r quare ent r ete a d oul mb per qua met r in th two ystems spect ely Se ELECTRICAL UNITS

Dielect i p l ati n ari e from the elect ical resp f di id al mol ul s f a med um a d may be clas fi d a el ctron t m orient tion a d sp ce-ch rg i t rfac l pol r at n a cord g to th m chan m i ol ed

El t o i p larizat on repre ents th d tortio f the le t n d tribut on motion b t tl n le an electr field Th p lar zation occur f r all m te al a d n arly i d p nd t f tem p r tu e nd f q ency p to ab ut 10 cps f r i ulato

Atomic p lari at n ari es f om the cha ge in d p le m m nt a mpany ng th st etchı g f ll mic l bo l betw unl ke atoms i m l l Th mech m co t b te t p lar zat n at fre n e c es b low tho of th b at l mode of mole ule (b ut 10 −10 cp) F a di cu i of mol c l v bratio s e MOLECULAR TRL TURE AND SPEC R

O i nt t n p la zat n ed by th p t l al onme t f p la m lec les, that i m l cul s po e g per a e t d p l m m ts i n el tr field Th s me h ni m l ds t a temp tu d p d t mp nt of p la at n t low f q n ie

Sp -ch o i te f ial p l ti n cu wh n harg c r e s a e pre nt whi h can m g at appr iabl d ta th h d el ct ic b t wh h b c me t apped n ot d harg at a l t d Th p always n lts n d s t t f th ma n fi ld d i imp rtant ly t low f q e

S DIE ECTRIC CONSTA T EL CTRIC IELD SU CE TIBILITY ELECT IC

[R D W]

eral characteristics of the earth's magnetic field such as the north drift and counterclockwise rotation of India relative to the poles. Studies in geology and rock magnetism give evidence of past differences in location of the magnetic poles and of possibilities for location of the poles—for example the North Pole in Alaska during the Tertiary and during earlier geological times in India, as Vening Meinesz assumes (*see* ROCK MAGNETISM). However, observation and analysis of present data are insufficient to warrant considering that the hypothesis of polar wandering is completely established. For a discussion of nutational wandering of the terrestrial pole *see* NUTATION (ASTRONOMY AND MECHANICS). [W.A.H.]

Polar coordinate navigation systems

Systems in which one or more signals are emitted from a facility (or co-located facilities) to produce simultaneous indication of bearing and distance; also called Rho-theta systems. Since a bearing is a radial line of position and a distance is a circular line of position, the polar coordinate system always insures a position fix produced by the intersection of two lines of position which are at right angles to each other. Since the reference for both lines of position is at a common origin, computation for any course referred to this origin is simplified. *See* NAVIGATION SYSTEM, ELECTRONIC. [P.C.S.]

Polarimetric analysis

A method of chemical analysis based on the optical activity of the substance being determined. Optically active materials are asymmetric, that is, their molecules or crystals have no plane or center of symmetry. These asymmetric molecules can occur in either of two forms, *d* and *l*, called optical isomers. Often a third optically inactive form, called meso, also exists. Asymmetric substances possess the power of rotating the plane of polarization of plane-polarized light. Measurement of the extent of this rotation is called polarimetry. Polarimetry is applied to both organic and inorganic materials. *See* OPTICAL ACTIVITY.

The extent of the rotation depends on the character of the substance, the length of the light path, the temperature of the solution, the wavelength of the light which is being used, the solvent (if there is one), and the concentration of the substance. In most work, the yellow light of the D line of the sodium spectrum (5893 A) is used to determine the specific rotation.

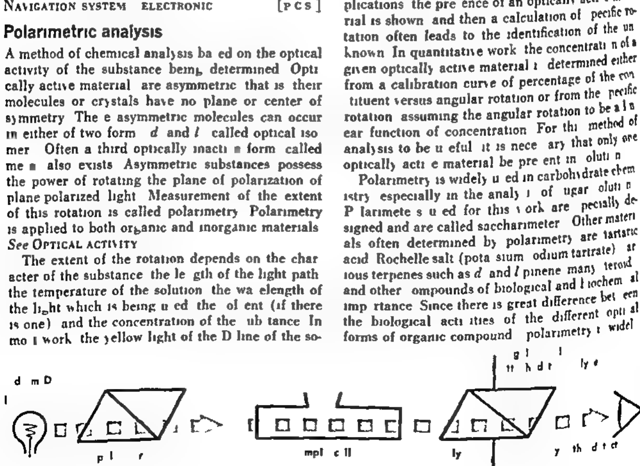
$$\text{Specific rotation} = [\alpha]_D^{0} = \frac{\alpha}{l\rho}$$

where α is the measured angle of rotation, l the length of the column of liquid in decimeters, and ρ the density of the solution. In other words, the specific rotation is the rotation in degrees which the plane-polarized light of the sodium D line undergoes in passing through a 10-cm-long sample tube containing a solution of 1 g/ml concentration at 20 C.

In the simplified diagram of a polarimeter light from the sodium lamp is polarized by the polarizer (a fixed nicol prism) before it passes through the cell containing the material being analyzed. After the light passes through the cell, it passes through the analyzer (another nicol prism) and then is detected by the eye or a photocell. A comparison of the angular orientation of the analyzer as measured on the scale with the cell empty and with the cell filled with solution serves to measure the rotation of the polarized light by the sample. This rotation may be either clockwise (+) or counterclockwise (−), depending on the substance in question.

Polarimetry may be used for either qualitative or quantitative analytical work. In qualitative applications the presence of an optically active material is shown, and then a calculation of specific rotation often leads to the identification of the unknown. In quantitative work the concentration of a given optically active material is determined either from a calibration curve of percentage of the constituent versus angular rotation or from the specific rotation, assuming the angular rotation to be a linear function of concentration. For this method of analysis to be useful, it is necessary that only one optically active material be present in solution.

Polarimetry is widely used in carbohydrate chemistry, especially in the analysis of sugar solutions. Polarimeters used for this work are specially designed and are called saccharimeters. Other materials often determined by polarimetry are tartaric acid, Rochelle salt (potassium sodium tartrate), various terpenes such as *d*- and *l*-pinene, many steroid and other compounds of biological and biochemical importance. Since there is great difference between the biological activities of the different optical forms of organic compounds, polarimetry is widely



Simplified diagram of a polarimeter

r ı th reflect vity at B ew ter a gle Th y s

$$I = B = A \quad c s \theta \qquad (5)$$

th mathemat cal st t ment f the law of

ar polarizing devices The angle θ an be s ed in the an le betwe n the tr n m tti g t p r f l n a pola When the po- s a e ps ll l they are t an p r nt When e c d the mb nat paq e The la ı we e gl s pl t s ı clined o that c d nt l ht w s at Brewste s ngle Such e e q ıte ın ffi ent nly mall ıt e f th ın de t lı ht ı r fl ted po l l ght M e effi ıent pola zer a be con ed

h c rystals C ta n nat ı l mate ıal ab l early p lar d l ght f n v brat n d rec m h m t ly than light ıbr ting t a les S h m ter l e termed d h ı ar describ d m e fully n nothe a tı le D cн оэ) To rm l n ıs one of th l st m d h cry tal and t urmal n plate ed a p l ri s f many ye r A p r was lly m u t d n wh t we k wn s t rmal n

In gent c yst l Oth atural m ter al t ı h h the el city f l ght depends the at nd t n The m t l as lled b r g The mpl t of th se s etu r crys- n wh ch th e ı ne d e t f p pagati wh h the light el ty ı ı d pe d nt of t e f p l ı t n Th te te med u ax al ls a d the p pag t n dı e t o mentı d all d th pt x ı F r ll other p op g t n t s the l t t r n be pl ı ı to mp n nt n ly ı pl c t g the l c a a d the th t r ght l s The light l c ty f a t e ı dex f r the e two wa e r t

O f the b t kn wn f th e h efr nge t y t a p nt al t (I land pa) a d a l p l t s ha e t e mad f m th ub e W N c l (1829) ı v nted the N l p ı m a h mad f tw p e f alc t me t d g th F g l Th m t Ca ada l am h h th w l c ty ı t rmed ıate bet e n ı y lact n l ıt f the f t d th l w Th a gl t wh h th l ght t k th b d h th t f r y the a gl of d e

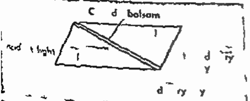


Fig 1 N l p m Th y f wh h S ll l w hold olled th d ry y

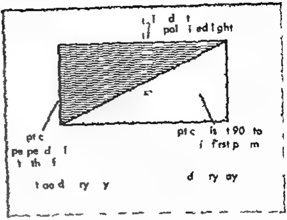


Fig 2 W ll t p m

ıs gr ater th n the cr t al ngl f r t tal reflect on Thu the comb ı tra sp rent f r nly ne polari zation dir tıo

Canada b l am is not completely transparent ın the ultra ıolet t wa le gth horter than 4000 a g t m Fu the mo l ge p eces f cal ıte ma terı l a e e c ed gly ra e A ern of p lar ers h s l n m de ı ı g q rtz, wh h ı tr n p re t n th ultrav olet nd wh ch ı mo mm nly a ailable n larg c s B ca e f the mall d f fe nce b twe the ref a tı nd e of q rtz a d Canad bal ar N l p m of q art wo ld be tr mend u ly l g f a g ı n l n ar ape t re

A d ff ent type of p l rı e mad of quartz, wa ın t d l y W ll W ll t n and ıs hown ın F g 2 Her the br ı ıı d ctı n are d ff t ın the tw p s that the tw rays a e d at d s th y pa th o gh the m te ı l Th ncoming l ght beam s thu epar ted nto two pp tely l nea ly pol d b ams wh ch h an ang l r epa ation betw n th m By ng appropr ate pt l st ps (bst le th t st t light ra s) the y tem o c n l cte ther b m

In the W ll st p m both b am a d ated a d ın e th q artz p duc s d pe sı ea h b m ı p e d nto a p t um This s not th a n a p ı wh ch w s ın ent d by A h n H th tw p e e are g d n F 3 O e be m p ed u de ated th gh th d a d th s h om t

She t p l n A th rd me h m fo bta n n p l ı ed l ht th P l ıd he t pol ı e t d by F H La d Sh t p l ız ı f ll ı t the e t pe Th f t s m r y t ll ne p l r wh h mall ry t l of d h r t al r ted p all l t a h th ı pla t m dı m Typ l m ry tal h e dle h p d qu nın d ulf t e mb dd d n a ı pla t a d o nt d by ext udı g th m te al th gh a sl t

Th d typ d p d f ts d h m n a p p rty of n d ı w t r l t Th o dı pp a s t f m al ea h gh p lym If th d ne p t a tr p nt ı nted l e t f m t al l a polyv yl l h l (PVA) the d

Polarization of waves

Polarization is the phenomenon which is exhibited when a transverse wave is polarized. The term polarization is also used to describe the process of polarizing a wave.

In an unpolarized wave the vibrations in a plane perpendicular to the ray appear to be oriented in all directions with equal probability. In a polarized wave the displacement direction of the vibrations is completely predictable. For certain disturbances, such as the transverse acoustic wave produced when a steel bar is struck, the polarization is complete. Electromagnetic radiation is normally unpolarized if it is generated by atomic processes (*see* ELECTROMAGNETIC RADIATION). Thus ultraviolet, visible, and infrared radiations produced by heated bodies or electrical discharges are generally unpolarized. Radiation generated by vacuum tube oscillators or transistor oscillators is always polarized. The probability waves (matter waves) associated with atomic or nuclear particles are generally unpolarized. *See* QUANTUM MECHANICS.

Some of the different types of polarization, as well as the technique of producing polarization in an unpolarized wave, are described in another article (*see* POLARIZED LIGHT). The electric vector can lie in a plane or it can follow a path whose projection at right angles to the direction of propagation is a circle or an ellipse. The same types of polarization can be produced in any transverse wave. For example, *see* MICROWAVE OPTICS.

Electromagnetic radiation is difficult to polarize in certain spectral regions, and few techniques exist for analysis. This is true in the ultraviolet below 1900 A. No dichroic polarizers have been found for this region, and transparent birefringent materials from which Nicol or Wollaston polarizing prisms could be made do not seem to exist. Polarization by reflection is possible, but very little work has been done with this technique. In the infrared region from the end of the visible spectrum to approximately 2μ, sheet polarizers exist. To around 4μ, polarizing prisms can be made. From 4μ to 80μ, reflection from a single plate or transmission through a pile of transparent plates is the common procedure. All these techniques produce linear polarization. Elliptical or circular polarization is more difficult to achieve.

X rays, photons, electrons, neutrons, and other particles can be polarized most easily by scattering. [B H BI]

Polarized light

Light which has its electric vector oriented in a predictable fashion with respect to the propagation direction. In unpolarized light the vector is oriented in a random, unpredictable fashion. Even in a short time interval it appears to be oriented in all directions with equal probability. Most light sources seem to be partially polarized so that some fraction of the light is polarized and the remainder unpolarized. It is actually more difficult to produce a completely unpolarized beam of light than one which is completely polarized.

The polarization of light differs from its other properties in that human sense organs are essentially unable to detect the presence of polarization. The Polaroid Corporation with its polarizing sunglasses and camera filters has made millions of people conscious of phenomena associated with polarization. Light from a rainbow is completely linearly polarized, that is, the electric vector lies in a plane. The possessor of polarizing sunglasses discovers that with such glasses the light from a section of the rainbow is extinguished.

According to all available theoretical and experimental evidence, it is the electric vector rather than the magnetic vector of a light wave that is responsible for all the effects of polarization and other observed phenomena associated with light. Therefore the electric vector of a light wave for all practical purposes can be identified as the light vector. *See* ELECTROMAGNETIC RADIATION; LIGHT; POLARIZATION OF WAVES. For information which is closely related to much of the ensuing discussion, *see* CRYSTAL OPTICS.

One of the simplest ways of producing linearly polarized light is by reflection from a dielectric surface. At a particular angle of incidence the reflectivity for light whose electric vector is in the plane of incidence becomes zero. The reflected light is thus linearly polarized at right angles to the plane of incidence. This fact was discovered by E. Malus in 1808. Brewster's law shows that at the polarizing angle the refracted ray makes an angle of 90° with the reflected ray. By combining this relationship with Snell's law of refraction one finds that

$$\tan i = n \tag{1}$$

where i is the angle of incidence and n is the refractive index. This provides a simple way of measuring refractive indices. *See* REFRACTION OF WAVES.

Law of Malus. If linearly polarized light is incident on a dielectric surface at Brewster angle (the polarizing angle), then the reflectivity of the surface will depend on the angle between the incident electric vector and the plane of incidence. When the vector is in the plane of incidence the reflectivity will be zero. When it is at right angles, the reflectivity will be at a maximum. To compute the complete relationship, the incident light vector A is broken into components, one vibrating in the plane of incidence and one at right angles to the plane.

$$A_\perp = A \sin\theta \tag{2}$$
$$A_\parallel = A \cos\theta \tag{3}$$

where θ is the angle between the light vector and a plane perpendicular to the plane of incidence. Since the component in the plane of incidence is not reflected, the reflected ray can be written

$$R = Ar \cos\theta \tag{4}$$

h e the refl cti ity at B te s angle The int ty is

$$I = B = A r \text{ co } \theta \quad (5)$$

Th is the m th m t cal t t ment f the l w of Ni l

Linear polarizing devices The angle θ can be d ed the a gle between the tr mitt g a es f a p f l e r pol zers When the po l rizer are p rallel they e tr pare t Whe th a e cr ed the mb tio op q ie The fi t p l riz s e e gla pl t s lined that th in dent l ght wa at B ewste s ngl Such polarize s are q i n fficie t i e only a mall p nt f th id t light is reflect d a po l rized l ght, M e ffi t p lar ers can be c n tru ted

D h o c e y tals Cert n atu l mat al b sorb h e ly p l ri d l ght of ne ibrat d ec t m ch m r tro ly th n l ght ib ati g at right a gles Su h materials a e t rmed d ch ic d de r b d m n fully i noth a ti le (*Dichro sı*) To rr l e s e f the best kn w d ch c y t l a d t mal e pl tes e ed a p l e s f m ny ye s A p ir was u u lly m u ted n wh t wer k own as t u m l e t gs.

B fr g t c y t l Oth r tu al m t al ex st hich th el c ty f l ght d p nd o th b t n d ect o The mat r al a e alled b re fri g nt The mpl t f these ir ct e ys tal in h ch the one d re t of p p g t o f r h h th l ght lo ty s i d pe d nt f t v te of pola i at n Th s a e t med n al ry t l nd th p pagat n d re t me t ned lled th pt a i F all oth p pag ti n d ect n the l tr ve t ca be pl t nto t c mpon t e ly n plan nta ng the pl ar d the th r t r ght gle The l ght lo ty l active i d f the tw wa i d ff t

O f th be t k n f th e b r f i g t rys t l i en ent ale t (l ela d p r) a l a te (p la h b m d i m th b ta W N l (1829) n ent d the N l pri m h h made f tw p e f l t m ted t g th F g 1 Th me t i Ca d b l am h h the w el ty term d t bet e th loc t e l it f r th f t d th l w y Th a gl t wh h the l ght t ke th l d ary h th t f ray th gle f de

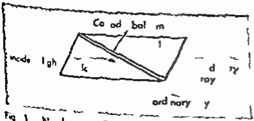
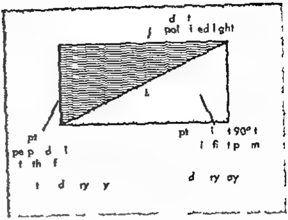


Fig 1 N l p m Th y f wh h S ll l w h ld b ll d h d ry y



Fg 2 W ll t p m

s g eate tha the crit cal angle f r t tal reflect n Thu the h mb m t anspa ent for o ly ne pol i zat on di ect n

C nad bal am is ot c mpletely tran parent i the ltr i let at w elength hort r th 4000 ang trom Furtherm re large p ece of al te ma ter l a e x eed ngly ra e A r e f p l r r has b e made t i g q tart wh ch i tr par nt in the ultra iolet a d wh h i r r omm ly avail bl n l rge p e B a se of the sm ll dif f ce b twee th r f t e i di of ir n nd Ca da balsam a N ol pri m f q rtz w ld be tr m nd ly l g f g e l ne r p rt re

A d ff nt typ of p la r made f quart w ted by W H W lla t n a d i hown n F g 2 H re th b t on d e t o e d ff r t in th two piece s that th tw r y are de i ted s th y pa thr ugh the m te ial The i m ng l ht beam s th s parat d nto tw pp tely l nea ly pol ri ed be m wh h h an g l r s pa at n betw en them By s n app op at pt c l t p (b tacl th t est t l ht r) the sy tem o e a el ct th r b m

I the W ll t p m b th b am a e d at d and s n e the q a t p du d persi e h be m i p ad t pe t um Th i t th e s t p i m wh h w n e ted by A R ch Her th tw pi c s e r nged a F 3 O b m p d nde ted thr ugh th de e d th s ach m t

Sh t p l ri A th d m ha i m lo bt i g p la ed l ght th Polar d h t p l ri r ted by E H La d Sh t p la s f ll nt th ee typ The fi t mi ocry t ll e p l ri wh h m ll y t l f a d h i m t r l t d parall l to e h th pl t c med um Typ l m c ry t l ch a edle- hap d qu e d ullat a e mbedd d n a i pla t d a nted by tr d g th m t l th ugh l t

Th e nd t p d pe d f r t d h i m property f n od ne w t l t n The io d e pp a t f m a l n a h gh p l mer If th od pur a t a p t nted l e t f m te al u h a p lyv yl l h l (PVA) th d

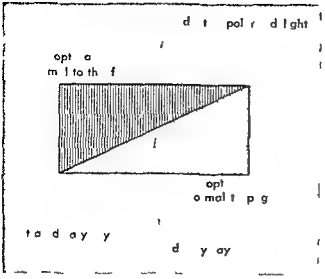


Fig. 3 Rochon prism

chains apparently line themselves parallel to the PVA molecules and the resulting dyed sheet is strongly dichroic. A third type of sheet polarizer depends for its dichroism directly on the molecules of the plastic itself. This plastic consists of oriented polyvinylene. Because these polarizers are commercially available and can be obtained in large sheets, many experiments involving polarized light have been performed which would have been quite difficult with the reflection polarizers or the birefringent crystal polarizer. See VECTOGRAPH.

Characteristics. There are several characteristics of linear polarizers which are of interest to the experimenter. First is perhaps the transmission for light polarized parallel and perpendicular to the axis of the polarizer, second is the angular field, and third the linear aperture. A typical sheet polarizer has a transmittance of 48% for light parallel to the axis and $2 \times 10^{-}$ % for light perpendicular to the axis at a wavelength of 550 mμ. The angular field is 60° and sheets can be many feet in diameter. The transmittance perpendicular to the axis varies over the angular field.

The Nicol prism has transmittance similar to that of the Polaroid sheeting but a much reduced linear and angular aperture.

Polarization by scattering. When an unpolarized light beam is scattered by molecules or small particles, the light observed at right angles to the original beam is polarized. The light vector in the original beam can be considered as driving the equivalent oscillators (nuclei and electrons) in the molecules. There is no longitudinal component in the original light beam. Accordingly, the scattered light observed at right angles to the beam can only be polarized with the electric vector at right angles to the propagation direction of the original beam. In most situations the scattered light is only partially polarized because of multiple scattering. The best known example of polarization by scattering is the light of the north sky. The percentage polarization can be quite high in clean country air. The late A. H. Pfund invented a technique for using measurements of sky polarization to determine the position of the sun when it is below the horizon. See SCATTERING (ELECTROMAGNETIC RADIATION).

Types of polarized light. Polarized light is classified according to the orientation of the electric vector. In linearly polarized light the electric vector remains in a plane containing the propagation direction. For monochromatic light the amplitude of the vector changes sinusoidally with time. In circularly polarized light the tip of the electric vector describes a circular helix about the propagation direction. The amplitude of the vector is constant. The frequency of rotation is equal to the frequency of the light. In elliptically polarized light the vector also rotates about the propagation direction, but the amplitude of the vector changes so that the projection of the vector on a plane at right angles to the propagation direction describes an ellipse.

These different types of polarized light can all be broken down into two linear components at right angles to each other:

$$E_x = A_x \sin(\omega t + \varphi_x) \qquad (6)$$
$$E_y = A_y \sin(\omega t + \varphi_y) \qquad (7)$$

where A_x and A_y are the amplitudes, φ_x and φ_y the phases, ω is 2π times the frequency, and t is the time. For linearly polarized light

$$\varphi_x = \varphi_y \qquad A_x \neq A_y$$

For circularly polarized light

$$\varphi_x = \varphi_y \pm \frac{\pi}{2} \qquad A_x = A_y$$

For elliptically polarized light

$$\varphi_x \neq \varphi_y \qquad A_x \neq A_y$$

In the last case it is always possible to find a set of orthogonal axes inclined at an angle α to x and y along which the components will be $E_{x'}$ and $E_{y'}$ such that

$$\varphi_{x'} = \varphi_{y'} \pm \frac{\pi}{2} \quad \text{and} \quad A_{x'} \neq A_{y'}$$

In this new system the x' and y' amplitudes will be the major and minor axes a and b of the ellipse described by the light vector and α will be the angle of orientation of the ellipse axes with respect to the original coordinate system. The relationship between the different quantities can be written

$$\tan 2\alpha = \tan 2\gamma \cos \varphi \qquad (8)$$
$$\sin 2\beta = \sin 2\gamma \sin \varphi \qquad (9)$$

where

$$\tan \gamma = A_y/A_x \qquad (10)$$
$$\varphi = \varphi_y - \varphi_x \qquad (11)$$
$$\tan \beta = \pm b/a \qquad (12)$$
$$A_x^2 + A_y^2 = a^2 + b^2 \qquad (13)$$

These same types of polarized light can also be broken down into right and left circular components or into two orthogonal elliptical components

Th se d fferent t r bases ar ef l n d ffere t phy l t at ns

Production of polarized light Linear polarizers h al eady been di cu ed Ci c l ly d ellip u lly p l d l ht e m lly p d ced by comb a l e polariz r with a wa plat A F esnel rh mb b u ed to p od ce circ larly pol d l ght

W pl te A pl t f m te l whi h l ea ly biref gent i ll d a w pl te or retardat heet. Wa plates h e a p r f thogonal axe b ha d (en t d fast a d l w P la d light th t el tri e t r p llel t the fast a i tr l f t tha l ght p l ri ed p rallel t the sl w

The th ckne of the mate l can b hose so that f r l ght t e g th pl te th is a d fi nt ph e li ft between the fa t comp n nt a d th l w mp e t A pl te w th a 90 ph s hift i termed a q rt wa e pl i The et d t on m g e by the p e n

$$\delta = \frac{(-)d}{\lambda} \qquad (14)$$

h e $-$, s th b ef g ce the slow i de t w elength λ n_f i the f l index and d is the pl i th ckne

Wa e pl tes can b made by preparing X cut ec tion f q t calcite otl er l iref ingent cry tals For r ta dati ns of le s tha few wave it i s sie t t sheet f iented pl tic or f plit m c A q a te wa e plate for th i il l nfra r d is easy t fabr te from m ca Tl e pla tic wrapp s from m ny Ame ican garette p ckages eem t h e alm t exa tl a half wa e r t rdat n f gr e l ht S e mica not tr n pa e t in the ultraviolet a small etard tio in this egi n i mo t easily achie ed l y cro g t o quartz plate wh ch differ by the r qui ite tl i k e

Linearly polari ed l ht i dent norm ll n a q rter w e plate and m ted at 45 t the fa t a is a be plit i t two equal ompone t paral lel to th fa t a d sl w a es These c n b rep e ented b f re p ss g the ugh the pl te by the quat s

$$E = A \quad n\ (\omega t + \varphi\ ) \qquad (15)$$

$$E = A \quad si\ (\omega t + \varphi\ ) \qquad (16)$$

where x and y are p llel to the wave plate axe

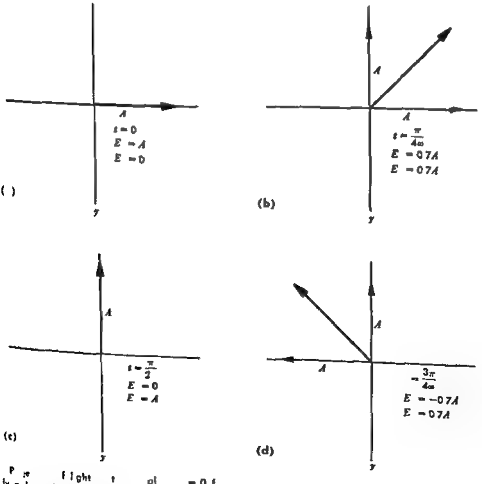


Fig 4 P je f l ght t pl = 0 f culo ly p l ed l ght ( ) $t = 0$ (b) $t = \pi/4\omega$ ( ) t 2ω (d) $t = 3\ /4\omega$

After passing through the plate the two components can be written

$$E = A \sin\left(\omega t + \varphi + \frac{\pi}{2}\right) \quad (17)$$

$$E = A \sin(\omega t + \varphi) \quad (18)$$

where E is now advanced one quarter wave with respect to E

One can visualize the behavior of the light by studying the sketches in Fig 4 which show the projection on a plane $= 0$ at various times It is apparent that the light vector is of constant amplitude and that the projection on a plane normal to the propagation direction is a circle If the linearly polarized light is oriented at -45 to the fast axis the light vector will revolve in the opposite direction Thus it is possible with a quarter wave plate and a linear polarizer to make either right or left circularly polarized light If the linearly polarized light is at an angle other than 45 to the fast axis the transmitted radiation will be elliptically polarized When circularly polarized light is incident on a quarter wave plate the transmitted light is linearly polarized at an angle of 45 to the wave plate axes This polarization is independent of the orientation of the wave plate axis For elliptically polarized light the behavior of the quarter wave plate is much more complicated However as was mentioned earlier the elliptically polarized light can be considered as composed of two linear components parallel to the major and minor axes of the ellipse and with a quarter wave phase difference between them If the quarter wave plate is oriented parallel to the axes of the ellipse the two transmitted components will either have zero phase difference or a 180 phase difference and will be linearly polarized At other angles the transmitted light will still be elliptically polarized but with different major and minor axes Similar treatment for a half wave plate shows that linearly polarized light oriented at an angle θ to the fast axis is transmitted as linearly polarized light oriented at an angle $-\theta$ to the fast axis

Wave plates all possess a different retardation at each wavelength This appears immediately from Eq (14) It is conceivable that a substance could have dispersion of birefringence such as to make the retardation of a plate independent of wavelength Such material has not yet been found

Fresnel rhomb A quarter wave retardation can be provided achromatically by the Fresnel rhomb This device depends on the phase shift which occurs at total internal reflection When linearly polarized light is totally internally reflected it experience a phase shift which depends on the angle of reflection the refractive index of the material and the orientation of the plane of polarization Light polarized in the plane of incidence experiences a phase shift which is different from that of light polarized at right angles to the plane of incidence Light polarized at an intermediate angle can be split into two components parallel and at right angles to the plane of incidence and the two components mathematically combined after reflection

The phase shifts can be written

$$\tan\frac{\varphi_\parallel}{2} = \frac{n\sqrt{n^2\sin^2 i - 1}}{\cos i} \quad (19)$$

$$\tan\frac{\varphi_\perp}{2} = \frac{\sqrt{n^2\sin^2 i - 1}}{n\cos i} \quad (20)$$

where $\varphi_\parallel$ is the phase shift parallel to the plane of incidence $\varphi_\perp$ is the phase shift at right angles to the plane of incidence i is the angle of incidence on the totally reflecting internal surface and n is the refractive index The difference $\varphi_\parallel - \varphi_\perp$ reaches a value of about $-/4$ at an angle of 5? for $n = 1.50$ Two such reflections give a retardation of $-/2$ The Fresnel rhomb shown in Fig 5 is cut so that the incident light is reflected twice at 5? Accordingly light polarized at 45 to the principal plane will be split into two equal components which will be shifted a quarter wave with respect to each other and the transmitted light will be circularly polarized Nearly achromatic wave plates can be made by using a series of wave plates in series with their axes oriented at different specific angles with respect to a coordinate system

Analyzing devices Polarized light is one of the most useful tools for studying the characteristics of material The absorption constant and refractive index of a metal can be calculated by measuring the effect of the metal on polarized light reflected from its surface *See* REFLECTION (ELECTROMAGNETIC RADIATION)

The analysis of polarized light can be performed with a variety of different devices If the light is linearly polarized it can be extinguished by a linear polarizer and the direction of polarization of the light determined directly from the orientation of the polarizer If the light is elliptically polarized it can be analyzed with the combination of a quarter wave plate and a linear polarizer Any such combination of polarizer and analyzer is called a polariscope As explained previously a quarter wave plate oriented parallel to one of the axes of the ellipse will transform elliptically polarized light to linearly polarized light Accordingly the quarter wave plate is rotated until the beam is extinguished by the linear polarizer At this point the orientation of the quarter wave plate gives the orientation of the ellipse and the orientation of the

Fig 5 Fresnel rhomb

poları e g s th r t of the maj t the m n a Kno ledg f the o ı f the llipt cally p lur d l ght lly g v s th r e t t n f th mpo ent h h pr duc d t nd from the vari item th pha e h fts and attenu t n produced b the exp rime t can be deduc d

O e of th b t k w tools fo wo k ng with p l rized l ht the Bab net ompen ator Th s de ı rm lly made f tw q ı rtz p ı m put t g th a h mb O e p m ı c t w th the ptic a ın th pl of n d n f the p m a d th oth ith the opt c pe ı nd cula t the plane f ın d The eta d tı n ı f ct on f d s ı eal ng the homb ıt w ll be e o t the cente arıng to p ıtı e a d n g tı e lu n pp ıt d ect s l ng the rh mb It can be used tc a cel the kn n r unk own eta d t o f n wa e plate

Retardation theory It d ffi lt t ntu ıvely th ffect of r f r ta datı n plates even f gle pl t f ge ral ret rdatı n δ on l ght h h n rm ll ı c dent n th plate d h h ıs pol z d ın a ge l fa h on This pr b l m ı mn t e ly l ed alg br ally The ı gle a pl te ıs umed t b o nt d n rmal to the d ect f p p g tıo f the l ght which s tak n t b the d ctıo f a et f C rtes an o o d t It f t ıs t an ngl α to th x ıı Th dent l ht ca b pre ted b th eq at on

$$E = A \quad n (t + \varphi) \qquad (21)$$
$$E = A \quad \text{ın} (\omega t + \varphi) \qquad (22)$$

A fir t st p ıs to b eak the l ght up ınto c mpo nt E a d E parallel t the of the plat On r te

$$E = E \ c\ s\ \alpha - E \ s\ n\ \alpha \qquad (23)$$
$$E = E \quad n\ \alpha + E \quad \alpha \qquad (24)$$

These c mp ne t c n l b w tten

$$E = A \ s\ n (\omega t + \varphi) \qquad (25)$$
$$E = A \quad n (t + \varphi) \qquad (26)$$

Aft r p ng th o gh the pl ı the omp t bec m

$$E = A \quad (\omega t + \varphi + \delta) \qquad (27)$$
$$E = A \quad (\omega t + \varphi) \qquad (28)$$

I gene l ıı f nter st t mp re the tp t th th p t Th tr m tted l ght s th b k n d n l ı mpon nt l g the gın l axes Tl s r h ı the eq at s

$$E'' = E \ \cos\alpha + E \quad \iota\ \alpha \qquad (29)$$
$$E'' = -E \ s\ n\ \alpha + E \quad \alpha \qquad (30)$$

W th th t of eq t o ıt ıı ıbl ı com p t th eff t f a w pl t ny f m of po l zed l ght

J l l s Equ t (29) a d (30) t ll b om o h lm ngly mpl t d y y t m m l g en al pı l el m ts Vari meth ad h e lee dev l p d t mplify th p blem d bl ı m k m ıı er l zat bo t ı ı m l l m t On f th m t st ghtfo

wa d p po d by R C Jone n ol es red cıng Eqs (29) nd (30) t matrıx f rm The Jo ı cal culus for opti al y tems ınv l es the polar zed elect c c mpo ent f the l ght ı t r and s d tın u l ed f om othe meth d ın that ıt takes c g nızance of the ab lute phase f the l ht wa e

The Jo e calculus write the l ght e t ı c m plex f m

$$E = A_x e^{(+)} \qquad (31)$$
$$E_y = A_y e^{(+\varphi_y)}$$

ıı

$$E = \begin{vmatrix} A_x e \\ A \quad \varphi_y \end{vmatrix} e^{i\omega t} \qquad (32)$$

M trix ope at rs a d v l ped f r diffe nt pt al elements Fro ı Eq (21) t (30) the p rator for wa e plat c n be de ı d dı ectly S e MATRIX THEORY

The J ne calcul dı a ly u d n mal ed f rm which mplifies the matr ces t a on der ble exte t In th f rm the terms ın v l ng the ctual mplit d a d ab lute pl a e of the ecto s a d ope ators are facto d ut of the expre sı s Th ı ten ıty of the light beam ı re d c d t un ty n th ı normal zed ve to so that

$$A + A = 1 \qquad (33)$$

Unde this ar ngement the mat ces f a ou types of pe tı n can be w tten

$$G(\delta) = \begin{vmatrix} e^{(\delta/2)} & 0 \\ 0 & e^{-(\delta/2)} \end{vmatrix} \qquad (34)$$

Th ıs the ope ato fo a w e pl te f r tard tı n δ nd with a es alo g x and y

$$S(\alpha) = \begin{vmatrix} \cos\alpha & -\sin\alpha \\ \sin\alpha & \cos\alpha \end{vmatrix} \qquad (35)$$

Th s s th ope at fo ot to wh h rotate l n a ly pol r zed l ght th gh n le α

$$P_h = \begin{vmatrix} 1 & 0 \\ 0 & 0 \end{vmatrix} \qquad (36)$$

Th s ı the op to fo pe fe t l nea polarızer parallel to th x ax A wa e pl t at an a gle α a be pr t d by

$$G(\delta\ \alpha) = S(\alpha) G(\delta) S(-\alpha) \qquad (3\ )$$

A e s of pt c l el ments be r p e ted by th ıı du t f a s s of m tr Th mpl fie eno m ly the t k f c mp t ng th ffect of ma y el m t It ı al p ble w th th J c l lu t d a se es f g al th orem c n cer ı g mb t ns of ptı al eleme ts Jo e h de b d th ı f the all of wl h pply nly f r mo ı h omatı light

1 An ptı al y tem c n t g of any n mb f ret dat plate nd r t t s ptı lly q ı al t t a y tem c t n ng ly tw l ment —one a r t rdat on pl te and th ı th ro tat

2 An pt al y t m ta n g ny numb f ı rt al pol z nd t t r pt ally q l t t a syst m c t ng nly two leme ts— a p rt al pol z d th othe r t t

3 An optical system containing any number of retardation plates partial polarizers and rotators is optically equivalent to a system containing four elements—two retardation plate one partial polarizer and one rotator

As an example of the power of the calculus a rather specific theorem can be proved A rotator of any given angle α can be formed by a sequence of three retardation plates a quarter wave plate a retardation plate at 45 to the quarter wave plate and a second quarter wave plate crossed with the first

$$S(\alpha) = S(\beta)G\left(-\frac{\pi}{2}\right)S(-\beta)S\left(\beta+\frac{\pi}{4}\right)G(\delta)S\left(-\beta-\frac{\pi}{4}\right)S(\beta)G\left(\frac{\pi}{2}\right)S(-\beta) \quad (38)$$

where β is the angle between the axis of the first quarter wave plate and the x axis and δ is the retardation of the plate in the middle of the sandwich

The first simplification arises from the fact that the axis rotations can be done in any order

$$S\left(\beta+\frac{\pi}{4}\right) = S(\beta)S\left(\frac{\pi}{4}\right) = S\left(\frac{\pi}{4}\right)S(\beta) \quad (39)$$

This reduces the equation to

$$S(\alpha) = S(\beta)G\left(-\frac{\pi}{2}\right)S\left(\frac{\pi}{4}\right)G(\delta)S\left(-\frac{\pi}{4}\right)G\left(\frac{\pi}{2}\right)S(-\beta) \quad (40)$$

Now $$S\left(-\frac{\pi}{4}\right)G\left(\frac{\pi}{2}\right) = \frac{1}{\sqrt{2}}\begin{vmatrix} 1 & -i \\ -i & 1 \end{vmatrix} \quad (41)$$

and $$G\left(-\frac{\pi}{2}\right)S\left(\frac{\pi}{4}\right) = -\frac{1}{\sqrt{2}}\begin{vmatrix} 1 & i \\ i & 1 \end{vmatrix} \quad (42)$$

When the multiplication is carried through

$$S(\alpha) = S(\beta)\,\frac{1}{2}\begin{vmatrix} e^{i\delta/2}+e^{-i\delta/2} & -ie^{i\delta/2}+ie^{-i\delta/2} \\ ie^{i\delta/2}-ie^{-i\delta/2} & e^{i\delta/2}+e^{-i\delta/2} \end{vmatrix} S(-\beta) \quad (43)$$

$$= S(\beta)S\left(\frac{\delta}{2}\right)S(-\beta) = S\left(\frac{\delta}{2}\right) \quad (44)$$

The rotation angle is therefore equal to one half the phase angle of the retardation This combination is a true rotator in that the rotation is independent of the azimuth angle of the incident polarized light

A variable rotator can be made by using a Soleil compensator for the central element This consists of two quartz wedges joined to form a plane parallel plate The lower wedge is cemented to a plane parallel quartz plate

Mueller matrices In the Jones calculus the intensity of the light passing through the system must be obtained by calculation from the components of the light vector A second calculus is frequently used in which the light vector is split into four components This also uses matrix operators which are termed Mueller matrices In this calculus the intensity I of the light is one component of the vector and thus is automatically calculated

The other components of the vector are

$$M = A_x^2 - A_y^2 \quad (45)$$
$$C = 2A_xA_y \cos(\varphi_x - \varphi_y) \quad (46)$$
$$S = 2A_xA_y \sin(\varphi_x - \varphi_y) \quad (47)$$

The matrix of a perfect polarizer parallel to the x axis can be written

$$P = \tfrac{1}{2}\begin{vmatrix} 1 & 1 & 0 & 0 \\ 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{vmatrix} \quad (48)$$

This calculus can treat unpolarized light directly Such a light vector is given by the expression

$$\begin{vmatrix} I \\ M \\ C \\ S \end{vmatrix} = \begin{vmatrix} 1 \\ 0 \\ 0 \\ 0 \end{vmatrix} \quad (49)$$

The vector for light polarized parallel to the x axis is written

$$\begin{vmatrix} 1 \\ 1 \\ 0 \\ 0 \end{vmatrix} \quad (50)$$

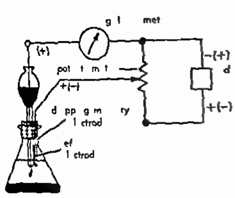
In the same manner as in the Jones calculus matrices can be derived for retardation plates, rotators and partial polarizers This calculus can also be used to derive various general theorems about various optical systems See FARADAY EFFECT INTERFERENCE OF WAVES OPTICAL ACTIVITY ROTATORY DISPERSION [B H B]

Bibliography M Born and E Wolf *Principles of Optics* 1959 F A Jenkins and H E White *Fundamentals of Optics* 3d ed 1957 R C Jones, The Sohncke theory of optical activity *J Opt Soc Am* 31(7) 488–503 1941 J Strong *Concepts of Classical Optics* 1958

Polarographic analysis

An electrochemical technique used in analytical chemistry Polarography is one of a group of techniques which are broadly classed as voltammetric The common feature of these techniques is that they all involve observation of current potential time relationships at electrodes immersed in electrolytic solutions The technique can be applied to any ionic or molecular species that is oxidizable or reducible in electrolysis within certain limits of potential Most metals and some organic functional groups such as aldehyde ketone amino and mercaptan may be determined by polarography

In conventional polarography the current through the electrolysis cell is measured as a function of the applied potential At sufficiently anodic (oxidizing) potentials no current is observed in the case of a reducible substance As the potential becomes more cathodic appreciable reduction occurs and the current rises in approximately exponential fashion Ultimately a potential is reached at which reduction occurs as rapidly as



P l g ph

th o molec les can r ach the electr de r f When th h ppe s the current le ls off at a l m tı g s l e ı d p de t f further ın rea e n pot nt al Thu the ur ent pot nt l curv or wa e ha s s gm ıdal hape The magn tude f the l m tı g cu e t ıs pr p t nal to th c nce tra t n f the edu ıble ub tan the te hn que h l e qu nt tatı analys s The half wa e pot tı l th p tent l at wh h the cu re t m d ay bet e n the r d l u r t (the cı re t t attrıb table to the ed ble bst n qu s t) d l m tı g cur e t plate often w th n f w mıll lts of th ta dard p te t l fo th lectr d e ctıo Ev n when t n t the half a e po t l t ll haracterı tı of the ea t ng pec so that qu l tatı e an ly s l o p ıble O dat are tud ed ı a anal us way

Apparatus The sy tem on t of a p tent m ter f adju t ng the p t tı l g l a m te f m a r g current a d a ell Th ll com m ly c taın t el t od s r f e c el trod (th cal m l l er l r chl r d) th p tential l which s o tant nd n nd e t lect od Th mo t widely u d p la g aph ınd t elect d s th dr ppı g m c y el t od (DME) whı h ı ts f fin b ap l lary tube abo wh h o tant h ad of me u y ı m ı ed Th m ury m rg fr m the t p of the ap ll ry at the r t of fe ll g am per ee d lı f rm aph c l d oplet wh h f ll f m th ap ll ry r fi e) to th l t t th te f n every 2 10 sec

Th n el elect ode ha a n mb r f g at ad t tages e the bl a a gem nt F t m cury ha a h gh hyd g ltage th t p oces es wh h uld be b ed b de mp ı tıon f w t r t oth r lect ode n b d ly b erved t t u fa Second th fa t th t the electrod f ı r n ed p dıc lly mea th t eprl cat d t cha g n rfa e m pr t n d r g the p oces a t u te ed Th sol t ın nt t w th these electrodes 10 to 10 mol r ın th elect t pec of m r m lecule nd nt ın add t on a l rge es (fifty) ld r g t) f uppo tı g elec t l t th r ı wh h does n t t at th lect od ın th pot t l r g o f ı te t. Th f tıo f th l tte t ed e th es t

of the lution and th s to en ure that diffusion m a ncentrat on gradı nt rathe than mıgratıon ın an ohm c potential grad ent ı th e m de f transfer f the specie t tl e el ctr de surf ce

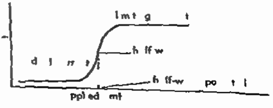
Applications Tl limitations of the potential range are et n the c thodic side by the red ıctıon of the l ent o uppo tı g elect olyte and on the an d c d by ıdatı n of the e or of the elec tr d materı l

The meth d ha bee u ed f r the determ natı n of m t m tal ıncl d n th e a a tıve s odıum a d pota ıum and for the d m at on f va ı us org nıc fu ct nal gr up ıncludın aldeh de ket ne h lo en d uble and tr ple bond nıt o n t so a hydrazo amın ulfides me capta s nd many others Be au e me cury on eact with ıı s an n anodıc dıs ol t n ur ents f mer u y an be used f r the determınatıon f hal de thıocyanate cyan de and ulfide am g othe Oxygen al du ed at the DME Alth gh th s f rm the ba ıs fo a conv n ent xyge determı a t on ıt m an th t solutı ns to be n ly ed for the c st t ts m st be pu ged of oxygen

A p lar g m can be pl tted m nu lly by ary ng th p te t l n fi te ınc ments and m asur n th c rr nt at each Alt rnat vely mme ıal n t ments r a ailable ın wh h th p tential ıs sc nn d by a moto d en l de w e a d the ur re t ıs co ded aut matıc lly The b rv d ur nt a of th o d r of few m roamp The a cu a y of a q ntıt t e analys s of tl o de f 1%

Other polarographic techniques Varı us elec t des th tha the DME h e b en u ed clud ıng d opp g tat g vıb at ng r stat o ary el tr de of t ng t n gold s l r pl tınum gall um g phıte m r ury r m rcu y amal am p ls r tat nary dr p and me ry pl ted pl t ı m d gold Alth gh ol d el ct des h e the d d a tage f g ıng rrat esult they n be ed at m h m re nod p te tıals th mercury

In add t on t th ent nal pote tı l c n meth d othe t hnıq es ba ed the same pr n ıple h e b n pplı d n ap al ıtuatıon So lled ll graphı p l ography n wh h alte atı u ent ( ) p te t ls applı d t the el ct d which c nve t nal p te t l c n pe f m d n l m ll ec nd l ss ıs particularly usef l wh r h gh t e t ıty desır d o whe th kı t f f t e t o s a tud d Con en t l cans wh ch m ll (a few mıll olts) n d l r squ re-wa e p te t al upe ım p ed the d ct urrent (dc) p t ntal a d the



P l g ph c ry

ac component of the resulting current is measured give curves which are essentially derivatives of the normal polarographic wave. These techniques are valuable in the study of multicomponent mixtures where the waves of the separate components are not sufficiently separated for conventional analysis. Inverse methods in which species are plated into mercury or onto the surfaces of solid electrodes and their dissolution currents measured have been applied to analyses of solutions as dilute as one part per 10^{9} parts of solution.

Many of these techniques are also useful for following the course of titrations. With a constant potential applied, the amperometric titration curve of current as a function of titrant added takes the form of two straight line segments with their intersection at the stoichiometric point.

Other voltammetric methods There are other voltammetric techniques in which current is controlled and potential is measured. If a linearly changing current is applied to a DME or rotated *solid electrode*, a curve of the same form as a conventional polarogram is obtained. This is current-scan polarography. A technique which has been known since 1878 but only assumed importance in the 1950s is chronopotentiometry. In this technique a constant current is applied to a stationary electrode in unstirred solution and the potential is measured as a function of time. The time at which a large potential break is observed is termed the transition time, and its square root is proportional to the concentration of the reacting species. If the data are plotted as square root of time versus potential, the resulting curve is of the same form as a conventional polarogram. *See* OVERVOLTAGE; TITRATION, AMPEROMETRIC. [W. H. R.]

Bibliography: I. M. Kolthoff and J. J. Lingane, *Polarography*, 2d ed., 1952.

Poliomyelitis

An acute infectious viral disease which in its serious form affects the central nervous system and, by destruction of motor neurons in the spinal cord, produces flaccid paralysis. However, about 99% of infections are either inapparent or very mild. *See* CENTRAL NERVOUS SYSTEM.

Infectious agent Polioviruses are no longer considered strictly neurotropic because (1) they will multiply in cultures of many nonnervous tissues, (2) viremia and antibody formation appear before the paralytic phase is reached and in cases where even transient signs of *central nervous* system involvement do not occur, (3) the virus is regularly found in the throat and stools before the onset of disease and after onset it is found for a week in the throat and for several weeks in the stools. The infectious virus particle is about 28 mμ in diameter. Freezing preserves it for long periods. In contrast to the arbor viruses, it is destroyed only slowly by alcohol and not at all by ether and deoxycholate. Poliovirus has a very restricted host range: most strains are *limited in host* to primates and in vitro to primate tissue culture (monkey kidney cells) are widely used. Three antigenic types of poliovirus are known, but most clinical cases are due to Type 1. *See* ANIMAL VIRUS; ARBOR VIRAL ENCEPHALITIDES.

Pathogenesis The virus probably enters the body through the mouth; primary multiplication occurs in the throat and intestine. Transitory viremia occurs; the blood seems to be the most likely route to the central nervous system. The events of the infection may range from a completely inapparent, through minor influenzalike illness, or an aseptic meningitis syndrome (nonparalytic polio*myelitis) with stiff and painful back and neck*, to the severe forms of paralytic and bulbar poliomyelitis. In all clinical types virus is regularly present in the enteric tract. In paralytic poliomyelitis the usual course begins as a minor illness but progresses, sometimes with an intervening recession of symptoms (hence biphasic), to flaccid paralysis of varying degree and persistence. When the motor neurons affected are those of the diaphragm or of the intercostal muscles, respiratory paralysis occurs. Bulbar poliomyelitis results from *viral attack* on the medulla (bulb of the brain) or higher brain centers, with respiratory, vasomotor, facial, palatal, or pharyngeal disturbances.

Diagnosis Laboratory diagnosis is by isolation, usually from stools inoculated into tissue culture, and subsequent identification by neutralization with specific antisera in vitro, and by complement-fixing and neutralizing serum antibodies. Isolation of a virus which is cytopathogenic in tissue cultures is not sufficient for diagnosis, *for many* other cytopathogenic enteroviruses also inhabit the enteric tract and produce syndromes similar to mild or early poliomyelitis. *See* CULTURE, EMBRYONATED EGG; CULTURE, TISSUE; NEUTRALIZING ANTIBODY.

Epidemiology Poliomyelitis occurs throughout the world. In temperate zones it appears chiefly in summer and fall, although winter outbreaks have been known. It occurs in all age groups but less frequently in adults because of their *acquired im*munity. In crowded underdeveloped areas and in tropical countries, where conditions favor a constant wide spread dissemination of virus, poliomyelitis continues to be a disease of infancy, and a high percentage of children over 4 years old are already immune. During recent decades in some areas of the temperate zone the age incidence has tended to change in marked parallel with improving sanitation and hygiene; exposure is postponed sometimes *so long that parents may be with*out immunity and succumb to infection transmitted to them from their children.

The virus is spread by human contact; the nature of the contact is not clear, but it appears to be associated with familial contact and with interfamily contact among young children. The virus may be present in flies.

Vaccine Salk vaccine (formalin killed), prepared from virus grown in monkey kidney cultures, has been widely used. It is not known how many booster inoculations are [illegible] to maintain immunity. F r th r a n a [illegible] n l t ha r

en f low p t n y at lea t fo n c lat s are comme ded A per n imm n ed with Salk a m y st ll bec me infected and arry virus in g t nt t n l tract

Exp m tal al a e n c ta n ng li e at m at d ıru h been de l p d b t ad quate t a ot y t av l ble o c rm n th ı genet c t b l ty alt r pas ng s m lly th ugh tl e v e ınee d h s ta ts a d th ınto th ommu ıty

The q e tio of safety of ny p l o accine pro ed of param t np tanc f the rı k of p g l l pol omy lıt fr m nat ı l ex po m ll In 1952 the f max mum f n the U t d St t nly n c e occ rred ry 3000 pe of all age and only one n ry 1000 f th h ld p pul t n [J L M]

B bl g phy I ter at o al Pol omyel tı Con gr *P l myel t s pap s nd disc ss o s p t d at th F th I te n t onal Pol my lıtıs C f ce 19 8*

Polishing

Th m oth ng of a u f by th cutt n a t n of a g t *the glued to o mp g ated* a fle ble h l belt P l hing ıs ot a p e p ore s nd t k s m d unt l th d s ed sur f c d t bta ed Wh ls r bu lt up f m layer f f t m t ıals uch a wo d l th r f l n a

Wh n a c n derable am u t f stock m t b r mov d perat s m y ta t with a o e r t b t fi er g t whe l fo fin h ng Comm n pol h g m h nes m y be e ther b nch o floo m nt d U u lly *they* a e l th type m h n s th wh el at *th* d of a p w p ndle ne d m y d n ab t e belt Va *ou typ s* f em t m t e p l t ma h e e u d f q nt y p d t on The e de ed t mo th w kp th gh the tt g pail f o m pol hing h ls S GRINDING

F m tl k fa a p e m br d g p res ll d pe fin h ı d S pe fin h g r m es m t flaws o ı *qualit* Wh le t n t p m ly t ded t mo e t k ge e ally d m n l h nge f 0001 0002 n n d m t k pl

The upe fi h ng pe at p f m d with tt emely fin gr t ab t n h ped ı m t h d r a l a g p t n f th wo k s f t th w kp t th st n r t os th k u d flood f l bri t n The p e u ally p f m d ymm trı al p re S L PPI MACHINING OPERATIONS

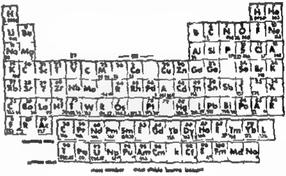
[A T]

Pollucite

A m al ıect l t w th mp t n C Al O H O P ll t ry t ll th met tem l r ll f med ry tal wh h a u ll rul h d t m t mm nl m Tl 6 6 *n* M h ac f d th p fi r ty l 290 Th m n l 1 l t what h tter t l ll t a m r l i d a pegmat t soc ated w th pod l pıdol t eucrypt te petal te a d e ı m beryl It ha b en found ın large m e at the Va u tra k pe matt ın Swe len I th Un ted Stat ıt w at ne time work d as a or of ce ıum at Newry Maine and in the Bl ck Hill f S th Dakota Se SILICATE MINERALS [C S HU]

Polonium

Elem nt numl e 84 ymbol P member of g oup VIb f th pe od c table Pol n m (P) was d red by Ma C r e (1898) ın pitchblende and named after he n t e c ıntry P land Th tope al o k wn as r dıum F ıs the p nult m t m mber of the radium dec y erıe pitchble d o ta n 01 mg/ton All polonium tope a e ad act e nd all are short l ved except the tl re *a* m tters I (29 yea) P (100 y rs) b th of wh ch a e pr d ced by bomb rd ng bı m th



w th de te ns a d natural P (138 4 day) n w prod ed ın mill ram am unt by the neu t n b mb rdm nt of b muth Pol n m *sepa t d f m bı muth by* pont eou dep s t ont a l n ble m tal u h as ıl f ll wed by a v uum ubl m tio or h m l p rat n of the d p t

Uses P l um (Po) s sed m ınly f the p od t on f n tr n ou e f the e the polo n m all yed with eleme t ch s b ryllium h ch ha s t pes f h gh *a n ro sect* It l b ed ı t t lm ato and wh o p at d ın th l ct ode all y *of pa k pl g* d t ımpo th ld st rı ng p operti s f nt l c mb t ng n s

Properties M t f the h m try of polo ıum h be n det m ned ı P l f wh h w gh 222 μg w k with w h bl am nts tl l e haza d nd q re p ci l te h n q e

P l m ı m met ll c th ıts lowe homo l g t ll um tw all t p e k wn α Po (imple b) d *β Po* (mpl h mbohedr l) w th the ph e cha g α→β at abo t 36 C. The *metal* ı h m lly m l to t ll m f m ng th b ıght red c mp d SPO nd S PoO a *n mb r f pol n d* re k wn The m tal ı oft d ıts ph l *pr p t es* mbl th e of thal l m lead nd b m th V le f 2 a d 4 ll establ h f nd th e m e d f h al P lon ı m l es b tw e l a d tel lu m n th lect ochem al

Compounds Two forms of the dioxide are known low temperature yellow face centered cubic (UO type) and high temperature red tetragonal It is formed from the element at 250 C and decompo es at 500 C under vacuum The black monoxide may be formed in the spontaneous decomposition of $SPoO_3$ and $SePoO_3$ The quadrivalent hydroxide (pale yellow gelatinou feebly amphoteric) is precipitated from olutions of polonium salts by alkalies it is reduced to the metal in alkaline su pen ion by hydroxylamine hydrazine odium dithionite and ammonia (liquid or concentrated aqueous solution) The last two reactions may be due to α radiation effect The brown bivalent hydroxide is readily oxidized Polonium monosulfide (black) i precipitated from acid solutions of polonium salts by hydrogen sulfide (olubility product $5\ 5 \times 10$) it decompo es to the elements at 275 C and 10μ pre sure a property utilized in the preparation of pure polonium metal

The halides are covalent volatile compounds resembling their tellurium analogs (PoCl yel low PoBr carmine PoI_4 black PoCl ruby red PoBr purple brown PoCl Br salmon pink) with the bivalent tate more stable than the quadrivalent the latter gives ri e to face centered cubic complex alts M_2PoX_6 (X = Cl yellow Br brick red I black) where M is a univalent cation The cesium salts are the lea t oluble The quadrivalent halide in olution are reduced to the bivalent state (pink) by hydrazine sulfur dioxide or ar enic(III) oxide (on warming) and to the metal by tin(II) chloride sodium dithionite or titanium (III) chloride C mplexe with organic molecules (for example tributyl phosphate dithizone ethylenediaminetetraacetate nitro yl chloride and ammonia are al o known

The increa ed metallic character of polonium as compared to tellurium is hown in the formation of the salts Po(SO) (white hydrated deep purple anhydrous) and $Po(NO_3)_4$ (white) Both are readily hydrolyzed the former to 2PoO SO (white when cold and yellow when hot) the latter to a eries of ba ic nitrates which may be p lymeric The ba ic alts 2PoO SeO and 2PoO CrO are al o kn wn they are anal gou to tellurium sulfate 2TeO SO There i ome evidence f r a normal chr mate (yell w $Po(CrO\ )$?) and a hexavalent polonium/chromium c mplex acid The a etate cyanide i date oxalate and ph phate (all white) have been prepared and there i e idence for the f rmation of a vanadate and tartrate

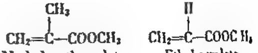
Determination Polonium (Po) i e timate l by it a emi ion either by direct counting or calorimetrically in the latter ca e the mea ure ment dep nds on the heat liberated by the t p page of the di integrati n α particles within the ample See NUCLEAR REACTION RADIOACTIVITY TELLURIUM [K W B]

Bibliography K W Bagnall *Chemistry of the Rare Radioelements* 195 K W Bagnall et al *The Polonium Chemistry Project* At mic Energy Re arch E tabl (Gt Brit) C/R 6 19 8

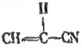
H V Moyer *Polonium* U S Atomic Energy Comm TID 5221 1956

Polyacrylate resin

U eful polymers can be obtained from a variety of acrylic monomer uch as acrylic and methacrylic acid their salt esters and amide and the corresponding nitriles The most important monomers are



Methyl methacrylate Ethyl acrylate

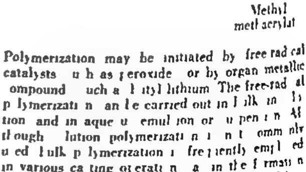


Acrylonitrile

Polymethyl methacrylate ethyl acrylate and a few other derivatives are di cu ed below See POLYACRYLONITRILE RESIN

Polymethyl methacrylate is di tingui hed a a hard tran parent polymer with high optical clarity high refracti e index and good re i tance to light and aging It and its copolymers are u eful for lenses signs indirect lighting fixture tran parent domes and skylights denture and protective c atings

The monomer may be prepared by the dehydration and methanolysis of acetone cyanohydrin



Acetone Acetone cyanohydrin Methyl methacrylate

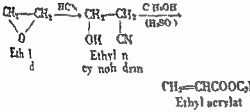
Polymerization may be initiated by free rad cal catalysts u h as peroxide or by organ metallic ompound uch a b ityl lithium The free-rad al p lymerizati n an be carried out in bulk in l tion and in aque u emul ion or u pen i n Al though lution polymerizati n i n t omm nly u ed bulk p lymerization i fre uently empl ed in various ca ting operati n a in the f rmati n of sheets r d and tul e in the mounting of bio l gical textile and metallurgical te t spe imen and in dental applicati n A 20 r ln ti n in l ume a c mpani th c n er n f m n mer t p lymer Thi make it d fficult t prepare articles t pr det rmine l dimen ions by th ca t polymerization te hnique Th pr bl m i largely minimized by u ing a yrup f p lymer l ol ed in m nomer or a dough of finely d ided p lym r dis p r ed in a relati ely small amount of m mer

Mold g p d r tt bl f r th nje t on molding of d al o name tal fixtu e and l n es m y be p p d from the g anule pr du ed by aqueo pen n p l m r ati n o from the pr duct of bulk polym izat

Sol i n f p lymethyl metha rylate and t polym rs ar u eful a la q e s Aqueous latexe f rmed by th emul i n polym ri t n of methyl m thac ylat w th othe m n me r sef l a t b ed p ints nd i th tre t ng f t xt le d] tl r

P l thyl a rylat i a to h omewhat r bbery p d ct The m m r us d m nly as the plas ti z g r often g i r d ent i cop lymer Th rel t ely h d r l th ry polym rs of methyl m thacrylate i yl etate yl chlor d an b made soft r by n rp at n of m derat m ts of ethyl a ryl te n the ri al p lymeri zat

Ethyl a ryl t may be pr du ed by the d hydra t n and eth ol s of ethylen ya ohydrin wh ch can be obt ed f m eth le e oxide



Th m n m r l p od d by th r a ti of a etyl e rb n m n xid a d ethyl alc h l n t pre ce of k l a b yl

P lym zati may be ff ct d by cat ly ts f th f e d l type Copolym at w th th mo m r a e f equ tly ted out in aq e ou em l n p

Oth ryl d i t es b b e th bject f t n ng int re t M thyl hl a ryl t d cy l h xyl m th rylat yield p lym w th la tivel h gh ft i g f nt d e t n t ser i h g The b tyl nd i l i f a l a d y ld rubbery mate l The add t o of p ly l uryl m th c yl te t pet le m l b i t g o l a a mp m t b th th fl w g p p ties l th l at low temp at nd the e st n t th ng t h gh t mp atu S e ACRY LO ITRILE I L STICS F CATION PO YMERIZA TIO

[J I L M H]

Polyacrylonitrile resin

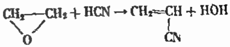
A h rd h rny l t ly l bl and h gh m lt ing mat l P lya r l it l (p lyv yl y d l t ed lm t enti ly in r lym The c poly mer [ ]] t th ee g up fib r pla t a d r bb Th p es f cryl t il a p ly mer mpo i f d t i ts re t t temper ti h m l mp t a d fl g

A ryl t i] g ner ll p red by e f the f ll i g m thod

(1) Cat lyzed add t l hydr g n yan de t et l n

$$CH{\equiv}CH + HCN \xrightarrow{Cat al} CH_2{=}CH{-}CN$$

(2) Re ct on between hydrogen cyanide and ethylene x de



(3) R a tion betwe n ammon a and pr pylene

$$2CH_3{-}CH{=}CH_2 + 2NH_3 + 3O_2 \rightarrow 2CH_2{=}CH{-}CN + 6H_2O$$

The p lym zati n of cryl n trile can be readily i tiated by m a s f the c n nt onal free ad c l ataly ts such as peroxid s by i radi ti r by the u f alkal metal at ly ts Alth ugh poly mer at n n bulk pr ceed t o rap dly t be c m me ally fea ible atisf ct ry co tr l f a p ly me izati n c p lym r at n may b h e ed in uspens n and n emul i n nd in aq eous olu tions f om wh ch th polym e p ec pit te C p ly me ta ning a ryl trile m y be fabric ted by th u ual m thods f ha dling the n pla ti res ns

The maj r f a ryl nitril i n the f rm of fib Th h h tre gth h gh s ften tempera tur e t ta e t g chem al wate a d cl n n l ent a d the lt wool l ke f l of fab cs ha e m de the product p pula f r m y u es uch as a l c rd g bl nkets a d ious type of lothi g C mmerc l f rm f the fibe n b bly re c polyme c ta ning mi am unts of othe inyl deri ti e such v l pyrr ll d v nyl c tate yl chlo acetate cr la m d o th r The m m r ar in l ded to pr d ce pecifi ffect uch a imp em nt of dye g q al ties

Exte v i m d f polymers of a rylon t le w th butad ene often c ll d B a N r bb s whi h o t n 15-40 cryl n trile M or amo nt of the un t rated e t s h as thyl a rylat wh h y ld a h yl gr up on hyd ly is ma b n porated t imp the ri g p op rti The B N rubbe ha i ta e to hydr a bon ol t u h as ga olin a d s tance t b a n nd in m se bow high fle bil ty t l w t m p tu es

I r t ye ble d f yl p lym n h s p ly ty e e polyv nyl chlor d w th m ll to m de at mount of cryl n tril r w th n a ry lo tr le-b t d en opolym h ve r pr nt d g fi a t d a ce i pol m r t hnol gy The p du ts mbine the h d s of the v yl polym r a d the imp t ta c of th bbery compo n t S m f the m y appl c t n a mold i g mpounds f r pr du t po es g h gh im p t e ta u h as p pe nd a h ts f t t l u e h a nd i l du ts r f ger tor l n d th ped c devi e S ACRYLO I

Compounds Two forms of the dioxide are known low temperature yellow face centered cubic (UO type) and high temperature red tetragonal It is formed from the elements at 250 C and decomposes at 500 C under vacuum The black monoxide may be formed in the spontaneous decomposition of $SPoO_3$ and $SePoO_3$ The quadrivalent hydroxide (pale yellow gelatinous feebly amphoteric) is precipitated from solutions of polonium salts by alkalies it is reduced to the metal in alkaline suspension by hydroxylamine hydrazine sodium dithionite and ammonia (liquid or concentrated aqueous solution) The last two reaction may be due to α radiation effects The brown bivalent hydroxide is readily oxidized Polonium monosulfide (black) is precipitated from acid solutions of polonium salts by hydrogen sulfide (solubility product 5.5×10) it decompose to the elements at 275 C and 10μ pressure a property utilized in the preparation of pure polonium metal

The halides are covalent volatile compounds resembling their tellurium analogs ($PoCl_4$ yellow $PoBr$ carmine PoI black $PoCl$ ruby red $PoBr$ purple brown $PoCl Br$ salmon pink) with the bivalent state more stable than the quadrivalent the latter give rise to face centered cubic complex salts $M PoX$ ($X = Cl$ yellow Br brick red I black) where M is a univalent cation The cesium salts are the least soluble The quadrivalent halides in solution are reduced to the bivalent state (pink) by hydrazine sulfur dioxide or arsenic(III) oxide (on warming) and to the metal by tin(II) chloride sodium dithionite or titanium (III) chloride Complexes with organic molecule (for example tributyl phosphate dithizone ethylenediaminetetraacetate) nitrosyl chloride and ammonia are also known

The increased metallic character of polonium as compared to tellurium is shown in the formation of the salts $Po(SO\ )$ (white hydrated deep purple anhydrous) and $Po(NO\ )_4$ (white) Both are readily hydrolyzed the former to $2PoO\ SO_3$ (white when cold and yellow when hot) the latter to a series of basic nitrates which may be polymeric The basic salts $2PoO\ SeO$ and $2PoO\ CrO$ are also known they are analogous to tellurium sulfate $2TeO\ SO$ There is some evidence for a normal chromate (yellow $Po(CrO\ )$?) and a hexavalent polonium/chromium complex acid The acetate cyanide iodate oxalate and phosphate (all white) have been prepared and there is evidence for the formation of a vanadate and tartrate

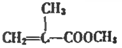
Determination Polonium (P) is estimated by its α emission either by direct counting or calorimetrically in the latter case the measurement depends on the heat liberated by the stoppage of the disintegration α particles within the sample *See* NUCLEAR REACTIONS RADIOACTIVITY TELLURIUM [K W B]

Bibliography K W Bagnall *Chemistry of the Rare Radioelements* 19 K W Bagnall et al *The Polonium Chemistry Project* Atomic Energy Research Estab (Gt Brit) C/R 2566 1958

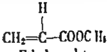
H V Moyer *Polonium* U S Atomic Energy Comm TID 5221 1956

Polyacrylate resin

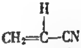
Useful polymers can be obtained from a variety of acrylic monomers such as acrylic and methacrylic acid their salts esters and amides and the corresponding nitriles The most important monomers are



Methyl methacrylate



Ethyl acrylate

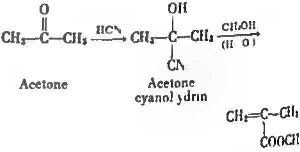


Acrylonitrile

Polymethyl methacrylate ethyl acrylate and a few other derivatives are discussed below *See* POLYACRYLONITRILE RESIN

Polymethyl methacrylate is distinguished as a hard transparent polymer with high optical clarity high refractive index and good resistance to light and aging It and its copolymers are useful for lenses signs indirect lighting fixtures transparent domes and skylights dentures and protective coating

The monomer may be prepared by the dehydration and methanolysis of acetone cyanohydrin



Acetone Acetone cyanohydrin Methyl methacrylate

Polymerization may be initiated by free-radical catalysts such as peroxides or by organometallic compounds such as butyl lithium The free-radical polymerization can be carried out in bulk in solution and in aqueous emulsion or suspension Although solution polymerization is not commonly used bulk polymerization is frequently employed in various casting operations as in the formation of sheets rods and tubes in the mounting of biological textile and metallurgical test specimens and in dental applications A 20% reduction in volume accompanies the conversion of monomer to polymer This makes it difficult to prepare articles to predetermined dimensions by this cast polymerization technique The problem is largely minimized by using a syrup of polymer dissolved in monomer or a dough of finely divided polymer dispersed in a relatively small amount of monomer

ge a d bea a d fo l tr c l m unt ng th y a e l us d fil m t b tle nd N l be and g rs p f rm q tly d ed l tl o l b t n

Th t at d f tty a d et ble l (fo ampl l l id) m y d m e p lyme e l polyme tl h their t t d g p Th d p l ca boxyl c d bta d y ld gh p ly m d b d att w th d p ly Thes p duct a empl y d t g d dh e d l d t ep d ph l c r f rm l t S PLASTICS FABRICA TIO POLY IERIZATION [J A L M H]

Polychaeta

A la f th A el d met m ll d Ch to- pod The an m e largely f l l t t l t e t (a t l or h l) l l t or pl kt th pe t d ep n b t t Th y f d ll pa t f th wo ld and or t ll d pth b t best k wn f m the pp 150 f th m

Taxonomy P ly h t l fied t 64 f m le t g bo t 1600 g e a nd 10 000 spe The a cc d g t th spec Th l gest t th p fam l E c d me s to 900 mm t le gth Th m lle t m g th A h l d me u l th n 1 mm Th tent f th r d e ty e mpl fied mm o g me ch s th f ll w l t

C mm m	*G us*
S m	*Amph t t Aph d t*
Lug m	*A e l*
F g m	*C t l*
P l bl dw m	*E Glyc*
Cl m w m	*N th N*
S d m	*N phty*
M d H t orm	*P l d*
F th d t r w m	*S b ll S p l*
C ll n rm	*P t*
Gooseberry rm	*St psi*
R f b lde m	*S bell ria*

Oth d pt e n me l d fi w m (th A ph m d e) l f tl t t ed l th l p t p t t th k d th t mh m (the M ld d) Th l g g p f P l h ta tl d d d t th F nt m n f l m l th Sed nt me n g t b l bt t th t m h n t t pl l g l p l t l e m y f th f t t b l a d m f th e l t The f th t m Ph ph l m g h d xp d d Crypto- ryh l h d l d p ll l th t f th fi t set f d lt imp ll t p t th t embl g f f m l pt t lly t p h th Apl d t f tl al b m th F f th th h t t l th Se p l f th w th p l d led Th l es th m j t f f l pece t led It t m t

plac the elyt l b rm aph d tid at on d d the ope c l ted e p l d at the th r Th l t nd cate th arran eme t currently d Err tia

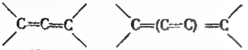
Scale w m d allied fam l
Aph d t d e
P lyn d
P ly d tid e
S l nidae
Pa eulepid
Ch y opet l d
P lmyr d
P n d e
Fi ew m and all d f m l
Ampl i omidae
E pl d e
Sp th d
Leaf worm d ll d pel c famili
Phyllodo d
Lop d hy chida
Iospil d
P todor d
L yd dae
Al p d
Typl l c l d e
T m pt d e (Gymnocop)
H d
P l d
Syll d e
N d
Nepht d e
Sph d d e
Gl e d
G n d d e
S pe f m l E ce
O ph d
E d
L mb d
A b ll d
L t d
D rv ll d
Pa t f m l
H t t bd ll d
I ht t m d
My t m d
M t m d
P t m t m d
M m t m d
St l h p d
S d t
O b d
P d
Ap t b h d
A t d w th p f l g p lp
Sp d
M g l id e
Lo m d
H m d
Cl t pt d
F w m
C t l d
Ct d l l

TRILE Plastics fabrication Polymer properties Rubber [J.A.M. L.M.H.]

Polyalkene

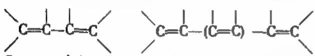
One of a class of *organic compounds containing* two or more ethylenic linkages in the molecule. These compounds are sometimes termed polyenes. They exist in accordance with one of the following three systems:

(1) The unsaturated linkages may be directly attached as in allenes or cumulenes and are said to possess cumulative unsaturation.



Allene Cumulene

(2) The unsaturated linkages may alternate with single linkages, in which case the unsaturation is said to be conjugated.



Conjugated diene Conjugated polyene

(3) The unsaturated linkages may be separated by one or more carbons, in which case the unsaturation is said to be isolated.

Isolated polyene

Allene compounds are mainly of interest in studies involving the stereochemistry of organic compounds, since it is possible to synthesize optically active compounds which are mirror images of each other. *See* Optical activity.

Conjugated dienes are the most important group of polyenes, since such compounds as butadiene, isoprene, and cyclopentadiene are included in this classification. *See* Diene.

Isolated polyenes include the unsaturated hydrocarbon squalene, which contains six isoprene units with six isolated double bonds. It is an aliphatic triterpene and is related to the carotenoids, such as lycopene, the red coloring matter in tomatoes, and carotene, provitamin A. *See* Alkene; Terpene; Triterpene. [C.A.C.]

Polyamide resin

A horny, whitish, translucent, high-melting polymer. Polyamide resin can be essentially transparent and amorphous when their melts are quenched. On annealing or cold drawing they become highly crystalline and translucent. The polymers are used for fibers, bristles, bearings, gears, molded objects, coatings, and adhesives. The term nylon refers specifically to those synthetic polyamides which are capable of forming fibers. *See* Fiber, man-made.

Brief outlines of the preparation of commercial polyamides by (1) the reaction of dicarboxylic acids with diamines, (2) the condensation of amino acids, and (3) the reaction of so-called *polymerized vegetable oil acids with polyamines* are given in this article.

Nylon 6,6 and nylon 6,10 are products of the condensation reaction of hexamethylene diamine (6 carbon atoms) with adipic acid (6 carbon atoms) and with sebacic acid (10 carbon atoms), respectively. By heating equimolar proportions of the two reactants, a polymeric salt is formed.

$$\underset{\text{Adipic acid}}{HOOC(CH_2)_4COOH} + \underset{\text{Hexamethylene diamine}}{H_2N(CH_2)_6NH_2} \rightarrow$$

$$\underset{\text{Nylon 6,6 salt}}{[\overset{+}{N}H_3(CH_2)_6\overset{+}{N}H_3\bar{O}OC(CH_2)_4COO^-]}$$

which on further heating yields the polyamide

$$H-\left(\overset{H}{N}-(CH_2)_6-\overset{H}{N}-\overset{O}{\overset{\|}{C}}-(CH_2)_4-\overset{O}{\overset{\|}{C}}\right)_n-OH + H_2O$$

Nylon 6,6, a polyamide resin

Because the end groups on the polymer can react *on further heating, as in melt spinning*, it is desirable to add a very small amount of a monoacid or monoamine to the polymerizing mixture in order to prevent the formation of material of very high molecular weight.

Nylon 6,6 and nylon 6,10 are used primarily for fibers; however, they are also employed in molding compositions.

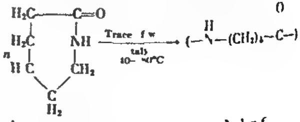
Nylon 6 and nylon 11 are obtained by the self-condensation of ε-aminocaproic acid and ω-aminoundecanoic acid, respectively.

$$\underset{\varepsilon\text{-Aminocaproic acid}}{H_2N-(CH_2)_5COOH} \rightarrow \text{Nylon 6}$$

$$\underset{\omega\text{-Aminoundecanoic acid}}{NH_2(CH_2)_{10}COOH} \rightarrow \text{Nylon 11}$$

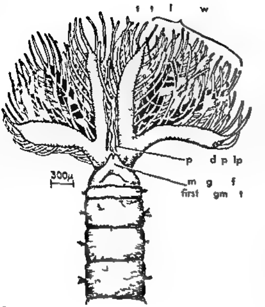
Each molecule containing both the amino and carboxylic groups can condense to yield high polymers by a reaction similar to that between the diacids and the diamine.

Nylon 6 can also be prepared by the polymerization of the lactam of ε-aminocaproic acid.



ε-Aminocaproic lactam Nylon 6

Nylon 6 and 11 are used mainly as molding materials and for the production of machine parts ... h



Fg 4 F b t d t l ew h w g feath ry w d p d p lp

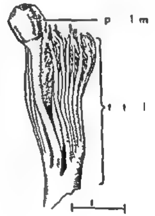
pe c l m (F g 5) f a p l d *Ch t p m* It m fu th m f the m p t rior egme ts t f rm a p f d gath A p r f m lle l ger p lp (F 4) e typ l pe t m l g s a d f tı n f d l t

Trunk The t k n m y Aphr d t ı ts f a d fi te n mb f gme t wh n Eu the ml d fi t w th f w 6 o m 7 0 gment Th y m y be s m la to th t f rm a l w rml ke bod r be mod fied ı t pec l z d eg h a th hd men or t ıl M t ll b dy egme t h v p ed ser f flesh l t ral xp sı f the body wall c lled p p d a They may be gl (m) r d ble (b r m u) ı t f d l b a h (not pod m) and tral b ch (eu pod um) Ea h h har t t lob oth r sof fl hy p ce n d a c l g t f rm f t n f t cl ı l t w l s f g b a h (F g 3) f ld (F 1) *P pod* Pa p d m s l pe et ated by ser ted od lled a la (e t l emb dded) b set e (me g t d r t t l) f h a ı t f m Set a e t f p c al z d ll th n th l a f p ap d They t n t dev l p th ugh t the l f f th ı d d l d a e pl ed qu ed Often th f m m lt pl se d ın m ny S d nt tl ma m th k r l l d es f ma h d ed (S p l O) Set h w t a d n d l pm t so th t *tt* fr po f le t d t fy a t pe F mples tl ml pect n e f a serpl ı d *Agl ph m* (F g 6a) d n b ı d (F g (f)) *D m* h b u h f ıq e f m ll poo l k set r t a p

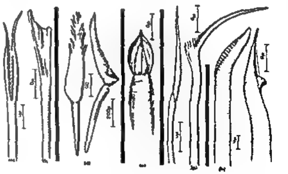
n *Phyl* Th op cul m f *Sabella ıa* ıs trength ened with p le hı h differ uter (F g 6c) and ınn r (Fıg 6*d*) r Many Sedentarıa ha e a ul hook or uncı pec lıar t famıly or ge neric gr up such as th e of tereb llıd (Fıg 7*a*) abell d (F g 7*b*) and rpı l d (F g 7)

Setae S tae m y be ımple (F 6*g*) comp te (Fıg 6*f*) Th y m y l e d tally ho ded (Fıg 6*h*) or t nsve ly r d e l (Fıg 6) The arı s kı d of tae f tıon n prog e ı n f r m ntaın ng g ıp for w mmın a n gans of defe se or of fen e d ın r productı phen mena In ome pe lag polychaetes etae a la kıng a d par podıa r m d fi d as p ddles ars I ome al worm th dor l etae e modified to form a d r al f lt nd ı me p lyod ntıd c mplex gl d l r o g n ec etes th threadl ke mesh wh h form th kly matted t be

Alimentary tract The al m tary t t shows m ny dep rt s f om a mpl yl drıcal t be An a te d r probo l ersıbl s a soft mple d ded p l a l ng rıchly



Fg 5 Ch t p m h w g t t l w d p c l m



Fg 6 V type f t ( ) P ct f a ph ty d *Agl ph m* (b) P t f d N ( ) P l f S b ll *a* f m t w (d) I w p l f S b ll ( ) Bru hl k pl m d t f m D m (f) C mp t t f th yll d E g (g) S mpl ta f th sab ll d F b (h) A h od d ( ) A dged et

Limivores
- Scalibregmidae
- Opheliidae
- Sternaspidae
- Capitellidae
- Arenicolidae
- Maldanidae
- Oweniidae

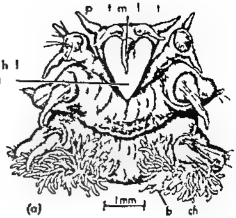
Anterior end with retractile oral tentacles
- Flabelligeridae
- Sabellariidae
- Pectinariidae (cone worms)
- Terebellidae
- Trichobranchidae

Feather duster worms
- Sabellidae
- Serpulidae

MORPHOLOGY

Head The head or prostomium may be a simple or secondarily annulated lobe in front of or above the mouth it may be pushed far back (Fig 1) or be retractile into one of the first few segments It may have simple eyespots or complex lenticular eyes Complex eyes are best developed in pelagic polychaetes Antennae are sensory threadlike structures (Fig 2a b) in various arrangements A caruncle or fleshy sensory organ is characteristic of many Errantia and is sometimes highly developed as in the fireworms *Hermodice* (Fig 3) and *Amphinome* (Fig 2a)

Peristomium The peristomium or first ring may be a simple mouth ring surrounding the mouth with its ventral part forming the lower lip or it may have setae and be variously modified to form complex structures Examples are the tentacular crown (Fig 4) of a sabellid *Fabricia* and the



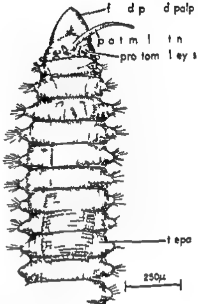


Fig 2 (a) *Amphinome* anterior end in dorsal view showing the prostomium ... first two segments (b) *E...gone* anterior end in dorsal view showing the anterior end of the alimentary tract with ...pan

Fig 1 Sp...ther... dorsal view showing the small prostomium set far back the dorsal ... and the transverse parapodial folds

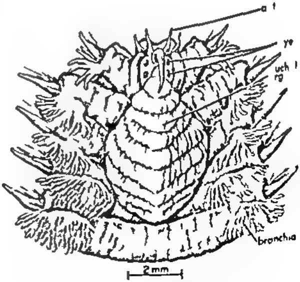


Fig 3 *Hermodice* anterior end in dorsal view showing the prostomium with four eyes ... median caruncle and parapodial lobes ...

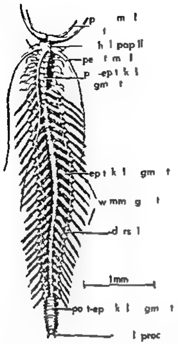


Fig 8 A t lyt m l p lyb t h p t k d rsol w h w g m d f d r g f th b dy

t f rm n p ul m l me e th l rv is f ee nd th d lt s d pted to mmen l m ex empl fed *Sp th* (F 1) n whi h th ad lt i g tly mod fied to l ta n k ds of po g

An eff t e b t l mm m th d f ep o d ct n by p t ri prolif at n u ly lled f dd g cha f m ti t a e efi io a d l gm t t N m s k d f y ll d a d m serp l d e w ll kn w mple S RE PR DUCTIO A I TAL

Regeneration Reg t o pl e m t of l t p t i ry tr gly de el ped P l ha te gen lly repl l t ga h p p dia tent ul r w r t l a d me curr t l d r t e t e d d al f m le eg m t A t t m th th w g ff of d m ged parts, f q tly p ed ege e t n S AU TONY REC RATI (BI LOGY)

FOOD AND ECOLOGY

Food M y p ly l t ed p t f ed s b st n n t t p t l c ta d n th b st t th oc upy La g m t e e g lf d by w p g t w th th d f bl p rt f th l m t ry t t N d g t bl f a t ar b r lled ll t d d th gl th an l part The l l t f A l me l n d l l h t k g mple f th la g m t f ed m t t ed p Ma Sede t filt feed l h h ghly m d fi d f l g th des s l tl t t l r f Se p l l T l lld d th l l g rs f t f m l d A l ry wh m f t t g p l f od t t l to

w d the mouth Ma y p lychaetes e pec ally th e with an e er bl p b have pecial ap t i g o l ldm d ice S h are the large f m d ble j w and p r th of many E n cea and N re d tl ey f t n n t only t pture l i g prey b t t g a p a d t r ff ble piece f lgae and the fo ms of ttached lif

Mo t p ly haete are f ee li ing b t m e p tly or ent ely depe d nt on an the an m l ei ther a c mm al (w thout app nt dam ge t the h t pecie) as a p a ite (more int mately ciat d with l t and pre um bly inj ou to it)

Am the c le wo ms some gener *Arcto H sp I p d sth a a d Hal yd* m g thers freq e tly a ciated w th ho ts f e le ted k d e t g e the e r o long me part f the h t wh ch rve a f d ca al Am n the E ce *Iphit m* occu the b an ch l chamber f la ge cr bs *Lab dog thu* is f nd th co l m f oth r p lychaetes the he si d *P da ke t* s ally a ciat d with cert n pe s f a t o d b t s met me f ee l v n All My o tome a e para t c n o n m t lid hi d m (ea l l es)

Ecology and distribution M st p ly ha tes are m ri e d ea h their p ak of b dan e i l tt al e of all ea They a e l gely t h l n th t i th y e t e w ter f t n lt o t ti A f w empl fi d b m r d phty d p tell d d bellid e e sh l n r an with ta d the f e h i g ffe t f tr am at th ffl e t t the Few e f e h w t r te l s be t k wn the Un ted St te mall bell d *M ay k a l idy* r g the ed me t f the G e t Lake d t b t e al g th e t n Atl t c t te

D t b t n f k d d t m ed by ch fa t s l t t d d pth t mp atur p im ty t l d m a d k d of ed m nt The firew rm ampl mids l g l t p c l i r mm n d n a a E n a d Ch t pte d e m i bu d t nd d i t p al d n t p l e b t ha m v r p t t e f differe t p es ld P ly d m lda id ph ty d d d l g ly tempe ate S e AN NELIDA FR SH WATER ECOSYSTEM MARINE ECO SYSTE I [O H]

B bl g phy W G Kuk nth l nd T K um ba h (d) *H db h d Z l* l 2 pt 1931

Polycladida

A l f m T l ell ia wh h e e l m ll m t t l e t m t l n th nd ll l fl ke b dy ha e t al t ti e w th d t g h a ch M t p l n the l tt l th l tt m aweed th bj ct mme l n th h ll f m ll k nd h m t ab N p a t Ex pt wa m t tl r ld m b ghtl l ed

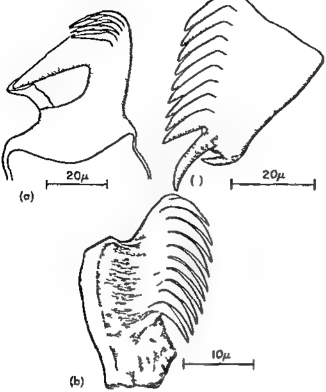


Fig 7 U cin of (a) *Amph t te* terebell d (b) *Fa b c a* a sab ll d ( ) *Ch t poma a* e pul d

adorned tul terminating distally in hard chiti nized jaws A part of the digestive tube may be in the form of a trepan (Fig 2*b*) In the Errantia it i usually more highly e ol ed than in the Seden taria in the former it i often e ersible in the lat ter eldom or never

Nervous system The nervou sy tem con i ts of a brain or dorsal cephalic ganglion connected to single or multiple entral cords by circume o phageal connective Various ramifications of this y tem innervate the fle hy meml ranes and form network of great complexity especially in hetero nereid epitoke stages In many Sedentaria the pe ri heral nervou sy tem i accompanied l y a giant fil er ystem functioning in phenomena of abrupt re p n e

Respiratory system The re pirat ry ystem is variou ly de elo ed and externally manifest a epi thelial outgrowths called l ranch iae or gill They are imple f lament or much di ided a in *Hermo dice* (Fig 3) Typically each l l is penetrated l y va cular l op making c nne tion with tran ver e ve el They effect a m re rapid exchange of xy gen with re pirat ry wa te

Circulatory system The circulat ry y tem con i t of median and longitudi al d r al and entral ve el continuou at either end nd with egmen tally arranged tran ver e c nnecti e extending to all part of the l ody The general directi n of fl w i f rward in the d r al and l ackward in th e ven tral ve el Pul ation emanates from a part of the dor al ve el which may be m dif ed a a heart A cardiac or heart l ody present in many S dentaria i m i cularized f ncti ning t stimu late more rapid flow of the blood Reduction of the va cular system to an open one occur in many Er rantia

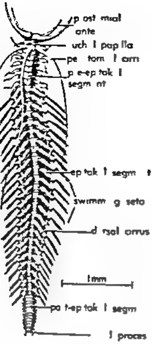
The blood may be colorle reddi h greenish bluish or yellow Recent studie by H Munro Fox have demonstrated the pre ence of a dichroic (red green) re piratory pigment called chl rocru rin which appears red in concentration and green in dilutions This is pre ent with red hemoglobin in at lea t ome pecie of *Serpula* Both pigment are allied to hemoglobin of vertebrate blood and d ffer in their reactions e pecially the degrees of affin ty for oxygen and carbon dioxide *See* RESPIRATORY PIGMENTS

Excretory system Excretion or elimination of liquid wa tes i accompli hed by egmental organ or nephridia In many Errantia they are clo ed at their inner ends and terminate in clu ters of mall cell called solenocyte Mo t Sedentaria and some Errantia have more highly evolved nephridia, in which the inner ending is a ciliated funnel and the tube is piralled or twi ted At maturity uch nephridia may function to relea e gonadial prod ucts

Reproductive system The reproducti e y tem may be imple or complex In the imple t form the sexes are eparate and the generative cells are pro liferated from the coelomic wall then hed into the coelom where the cell mature The external form of the body often changes either in col r or surface texture or a radical change may occur such as long swimming etae replacing normal ones Parapodial lol es may l ecome greatly en larged and many change l oth out ide and in ide the body cau e a metamorpho i Familiar exam ples are the heteronereid of the family Nereidae and the dimorphic pha es of the Syllidae illu trated by the polybo trichu (Fig 8) of the male and the acconereis of the female In these cases the adult i pelagic and called an epitoke whereas it nonpelagic pha e is an atoke

In ome polychaete uch as *Ophryotrocha* a shorter and younger male pha e i foll d l a longer and older female or change er fr m fe male to male pha es may re ult fr m al lati n of a po terior part In herma hr dite l th male and fe male element are concurrently pre ent u ually in different parts of the l ody and cro fertilizati n i ometime nece ary to en ure ial le ff pring

Relea e of ova may l e through p rial g nod t r through m dif ed nephridia r l y di rupti n f the l ody wall a in the al l w rm The fert l zed o um gi es ri e to a mall pl eri al cil ated larva called a troch pl ore which may mainta n a sh rt or long exi tence in the plankton Often the earl est tages are not planktonic l ut modif ed t d l p either in the tul e of the adult r in e ecial coc r egg cap ule Larval life may l e l rt r l varying fr m a f w h ur t m th Metam rph i fr m larval to adult tage may be grad al r al rupt a in *S l llaria* wl re an anteri r g al r pt l tel ed i t the fr t e ml m t



8 *Aut lytu* m l p lyb stnch pit k m
d ew sh w g m d fi d g f th b dy

rm an p lum I som es th l rv and th ad lt d pted t mm n al m ex lified in *Sp th (F 2)* n wh h the adult r atly modified t h ert n kin Is f

n ff tiv but les mm m thod f r p o- by posteri p l f t n. rr n.l d b dd ha f rm t n. t ex rse fi n. fr ment t n. mer k nd f yll d and erp lid ar w ll kn wn xamples S PE CTI TIAL.

egeneration P gener t pl ment f p rt. erv t l devel ped P l h etes rally pl l t h p podia. rol er wn tail d som rr tul ds t ent d d l f m l A totom th th win f d m ed s. f eqn tl p ecedes ner t n. S AT OMY PE E TIO (BI LOGY)

FOOD AND ECOLOGY

ood M poly h tes d p t feed b- ta they oc py Larg m unt ar engulfed by p t with th aid f ever bl part l mentary t t nd est bl f ctn n exp lled ally t ded th h th al t Th l d t f *I* n som t l bea hes trik g ex mples f th m t f sed ment t ed p M y S den filt *feed* d h h hly m d fied l gatheri des h th t t nlar f Serp l d Ter b ll d d th cili l grooves f p f rm a lid A liary h m f t n p p l food p rt les to- w d th m th M n p l haetes espec all those with an ev r H p b h ha pec l cap- t n h ld devi h are the l ge for m dable j w l p ra nath f m F n a a d Nere d they f t n n t l t ptur l in pre b t r gra p f t ff zaff p eces of lg d th r f rm of tt hed l f

Most polycha tes f eel g b t om are partl r ent el d pe dent n other a imal. es th mm n l (w th t pp t d ma to th host pec es) r a. para t (m r t mat l a ociated w th a host and pres mabl inj n to it)

Am g the scal worm som g *A ct H sp o L p d h a* d *H l ydna* am th rs freq tl a sociated w th host of se- lected k d t e th r ar l som p rt f th b t wh h rves a a food L Am g th E n ea. *Iph tim* occ r th bran ch al hambe of larg er bs *Lab d th s* f d t th oel m f th pol h etes th he d *P da k t* ll a soc ted with certa n pec es f terod b t a sometimes f eel All Myz t mes par t n r n comat l d ech oderm *t a l l es*)

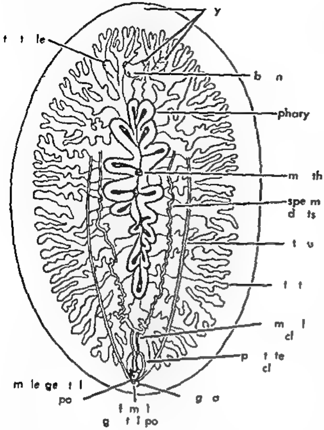
Ecology and d stribution M t pol h etes e m n a d h th peak f ab nd c n l tt al zo es f ll sea They ar l g l teno- h l th t t ther xt t se w t f cert n lt t t n A few empl fied b s m d n pht d p t ll d a d abellid urch l an withstand th f eshen n ffect f t eam t th t t t these Few f esh w t terri l n best kn wn t th U ted St tes t mall abellid. *Manay k a l dys* or rri th ed ment f the G eat Lakes and tribut ries I th ea tern Atl t t tes

D tnb t n f kind d t rm ed b h f c t as l t t d d pth. temper tu e pro im t to land ma se d k d f sedim nt Th firew rm mphi m d lar l t p c l r mmun *d n* a E n d Ch et pt rid m t b ndant d dw in t op l and ent p al zo es b t h ma y p esentat es f d fferent pec es n ld r se P l n d m lda d ph t d d d re larg l temper t S AN ELIDA FRE H WATE ECO-SYSTEM MARINE E O- YSTEM [O H]

B bl graphy W G K k thal a d T Krum b h (d) *H db h d Z l* l. 2, pt. -1931

Polycladida

A l f m m T b ll ri wh h ar several m ll m ter to sever l cent m ter length d whose leafl k bod ha entral testin with radiatin b hes M t pec es liv in th litt ral th bott m. n se w ed ther b t a mmen al. n th h ll f m llu k d her mit b are p t E pt in w rm w ter they ld m bri htl l ed.



Styl ch s ell pt u length to 150 mm (*Afte A S F a s* 1938)

Usually they have many eye and tentacles are frequently pre ent Frontal organs and tatocy ts are ab ent and adhe i e organ are rare The epi dermis i covered with cilia and contain numerous rhal dite gland Near the middle of tl e l ody i the mouth followed by the plicate j harynx which open into the central cavity of the inte tine The l rain lie anteri r to the pharynx with a numl er of nerves radiating fr m it but the tw ner e which parallel the pharynx are u ually the large t O arie and testes are numerou and cattered bu t y lk gland are lacking Sperm duct c nnect the te te with the copulat ry apparatu which i arial le in tru ture and often multiple rather than ingle In eminati n occurs through copulation or hy odermic impregna ti n The ent lecithal egg u ually a umulate in the a iduct or uteri and after fertilization pa to the exterior through the vagina Lang e i le a l ur a with a long talk i generally pre ent Mul ler s lar a the only free larval tage known in the Turl ellaria i f un l in me j olyclad l ut i lack ing in most Thi larva may indi t an e luti nary link l etween tl e Turl ellaria and the Ct noph ra and l etween tl e Turl ellaria and the Anneli la

Notoplana and *Styl chus* are tw of the large t and l est known genera f j olycla l witl repre entati e from l oth coa t f N rth Am rica In particular pecie of *Stylochi s* are oft n large forms 5 centimeter or m re in l ngth S e TUR BELLARIA [F R J]

Bibliog aphy H Stummer Traunfel *I olyclad ida* in H C Br nn (e l) *Klas n un l Or lnung n des Tierreichs* l 4 1930 1933

Polyester resins

Polymeric materials in which ester groups

$$-\overset{\overset{\displaystyle O}{\|}}{C}-O-$$

are in the main chain The aliphatic polyesters tend to be relatively oft and the aromati deri a tive are u ually hard and brittle or tough The properties of either group may be mod fied by cro linking cry tallization pla ticizer or fillers

The commercial product are alkyd which are u ed in paints and enamel un aturated polyesters or un aturated alkyd which are u ed exten i ely with fiber gla s for boat hulls and panels p l ethylene terephthalate which i u ed in the f rm of fiber and film and the aromatic p lycarbonates

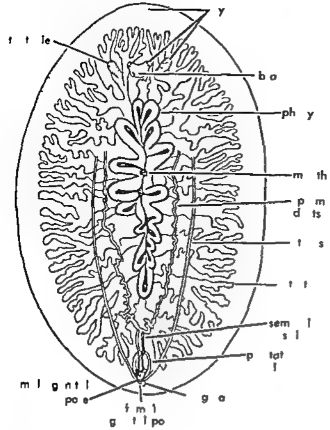
Thi article i devoted mainly to these f ur prod ucts The polydiallyl e ter are frequently li ted with the polye ters and will be briefly menti ned However their polymers are not true polye ters a defined above

Alkyds The alkyd have l een in common use as coating ince World War I In the l eginning they consisted almo t entirely of the reacti n product of *o* phthali anhydride and glycerol an l pigment Becau e the functionality of the y tem i greater than two a cro s linked in olul le p lymer is formed The fully cured product i quite hard and l rittle Flexil le and tough material can be pro duced by incorporation of monol a ic acid or monohydr xy alcohol in proportion ufficient to increa e flexibility l ut in uff cient to prevent c r ing Coml inations of conventional vegetable dry ing oil and alkyd re in repre ent the ba i of mo t of the oil olul le paint For example by heating a mixture of dehydrate l ca tor oil the glycerol e ter of linoleic acid with uital le pro portion of glycerol and phthalic anl ydride an il olul le j lye ter i f rme l A c mm n oil paint i produced l y the ad lition of tl inners uch a aromatic hydr carbon l ent a paint drier uch as col alt octoate and pigment By ex po ure to air in the pre ence of the paint dryer the un aturate l lien grou of the lin leic ester pol mer i e to yield a tough weather re i tant coat g S e DRYING OIL I OLYMERIZATION

The drying oil alkyd de cril ed ab ve may be furth r m difi l l y the incl i ion of a vinyl m nomer uch a tyrene in the original ester ficati n proce Some of the styrene p lymerizes j rhap a a graft p lymer and tl e r maind r j lymerize an l c p lymerizes in tl e final dr ing or uring of tl paint

Unsaturated polyesters The un aturated poly e ter wer level ped l ring and sh rtl aft r W rl l War II In c ml inati n with gla fiber th f un l immediate a lieati n a j an l ra t r d me boat hull an l pr tecti arm r f r l dier The c mp iti n are l ti gui hed l y ease f fal ri ati n an l l igh impact re i tan

Ph t m og ph f h m l t g wh d f m p ly
t mp d Ph t g ph d by D R m V h g g m t
f L m q pm t h gh-m g fi t m p d l ght p l
g q pm t (All d Ch m l C p)



Stylo hus ell pt c s Length t 150 mm (*Afte A S Pear 1938*)

U uall) they ha e many eye and tenta les are frequentl) pre ent Frontal organs and statocy ts are al ent and adhe i e organs are rare The epi dermi i covered witl cilia and contains numerous rhal dite gland Near the middle of the l ody is the mouth followed by the plicate j harynx v hich opens into the central cavity of the inte tine The brain lie anterior to the pharynx with a numl er of nerves radiating from it but tl e two nerve v hich parallel the pharynx are usuall) the large t Ovarie and testes are numerous and cattered l ut yolk glands are lacking Sperm ducts connect the te tes with the copulatory apparatus which is varial le in tructure and often multij le rather tl an ingle In eminati n occurs through copulation or hyp dermic impregna tion The ent le ithal egg u uall) a cumulate in the ovid ict or uteri and after fertilization j a to the exterior through the agina Lang e icle a l ur a with a long talk i generally pre ent Mul ler larva tl e only free larval tage known in the Turl ellaria i f und in me j ly lad l it i lack ing in mo t Thi larva may indicat a e l tionary link l etween th Turl ellaria and the Cten ph ra and l etween th T irl ellaria an l tl Annelida

Notoplana and *Stylochus* are two of the large t an l be t kn wn genera f polyclad witl repre ntati es fr m both c a t of N rth Am r a In particular p ie of *Stylochi s* are often l rge forms 5 centimeter or more in l ngtl S TUR BELLARIA [F R J]

Bil liography H Stummer Traunfel *I ly lad ida* in H G Bronn (ed) *Klassen und Or l ungen des Ti rreichs* vol 4 1930–1933

Polyester resins

Polymeric materials in which ester groups

$$-\overset{\displaystyle O}{\overset{\|}{C}}-O-$$

are in the main chain The aliphatic pol esters tend to be relatively oft and the aromatic deriva tive are usually hard and l rittle or tough The properties of either group may be modif ed b cro s linking crystallization pla ticizer or fillers

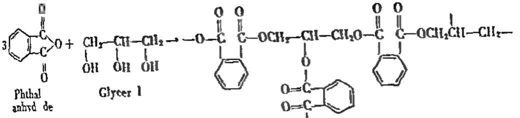
The commercial products are alkyd which are u ed in paints and enamel un aturated polyesters or un aturated alkyd which are u ed exten i el with fiber glas for boat hull and panels poly ethylene terephthalate which i u e l in the form of fil er and film and the aromatic polycarbonates

Thi article i devoted mainly to tl e e four prod ucts The polydiallyl e ter are frequently listed with the polye ters and will be briefly menti ed However their polymers are not true polyester a defined al ove

Alkyds Tl e alkyd have l een in common use a coating ince World War I In the beginning they con i ted almost entirely of the reaction produ t of *o* phthalic anhydride and glycerol an l pigment Becau e the functionality of the y tem i greater than two a cro linked in olul le polymer i formed The fully cured product is quite hard and brittle Flexible and tough material can be pro duced by incorporation of monoba ic acid or monohydroxy alcohols in proportions ufficient t increa e flexibility but in ufficient to prevent cur ing Coml ination of conventional vegetable dr ing oil and alkyd re in repre ent the la t of mo t of the oil olul le paint For example by heating a mixture of dehydrated ca tor oil th glycerol e ter of linoleic acid with suital le pro portions of glycerol and phthalic anhydride an oil olul le polye ter i formed A comm n oil paint i produced l y the additi n of thinners uch a aromatic hydrocarbon ol ent a pa nt drier uch a c l alt octoate and pigment By e po ure to air in the j resence of the paint dryer the un aturate l diene group of the lin leic e ter pol merize to yield a t ugh weather re i tant coati S DRYING OIL POLYMERIZATION

The drying oil alkyd de cril ed abo e may be further modified l y the inclu ion of a v nyl monomer uch a styrene in tl e original esteri fication proce Some of the tyrene pol m rize n chai a a graft p lymer and the remaind r polymerize and c p lym rize in tl e final dr i g or uring of tl e j aint

Unsaturated polyesters The un aturated poly ter were d el p d during an l h rtly after W rld War II In c ml inati n witl gla fiber they f un l immed ate aj j l cati n a p nels radar d m l oat hull an l pr tecti e arm r f r sol d r Tl e omp iti n are di tingui hed l y ease f fal ricati n and higl imj act re i tance



Phthal anhyd de Glycer l

Cro l nked res n

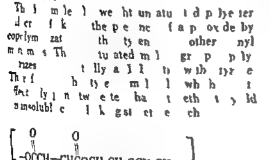
A l m lecul we ght unsat at d p lye ter t rmed t s fi t p od ed The re cti of m l c anhyd de th di thyl e glycol s type l

Mal anhydr d D thylen gl col

U t ted polyeste

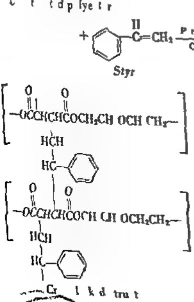
Th p od ct sco ol f m l l r w ight of 2000–4000

Th l m le l we ht un atu t d p lye ter d er f k the p e nc f a p ox de by copolym zat th ty en other nyl m n m s Th tu ated m l gr p p ly rizes t lly a l l ti w th tyr e Th r f h ty e m l l wh h t ffect ly j n tw e te ha t eth t y ld nsolubl c l k g st ct e ch



U t t d p lye t r

Styr



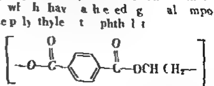
Cr l k d tru t

The mmerc ally vail l le i te medi te u satu rat d p ly ters i u lly c tain about 30% styr e r oth r i yl m n mer O addit n f a p oxide r ther fr e radic l ataly t a d a paint drier the copolym rizat n tart In thi tage the r in m y l e l a dled a a i u fl ud f r a few min te to a few h r d pend ng up n the acti ty f the cataly t The s u l q u l m y l a ppl d t gla s fib r (w th a pe ial rfa treatm nt) the f rm f matt t w r vi g r f th w tl p ecauti n t elim ate r l ul l le a d t oid l l l les that m y be u ed by rheating a a ult f too rapid uring The rfa e f the gla fl r m t h e bee g en a ç al fini h g tre tment in d vance f r the p lye ter t adhere tro gly Glass fib r tre t d with inyl l a o gano- h om ompl x mme ally a lal l

In th l f the p t dri xyg f the l a a i h i tting fi t n il i g proc s with the es lt th t the f e f the prod ct remain ft ft th n r p t l a e l rd ned l th p e ence f pa nt d ie l as b lt phth t th k in g eff t elimi t d

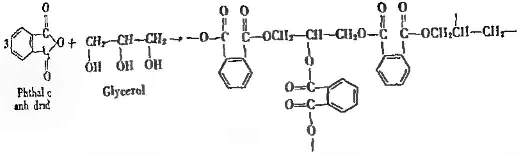
In recent yea a ml l m d fic t on of the c mp ll nde r b d b e ha l eer made Oth d th r glycol and ml ati ns may b d t y p p rtie u h fl b l ty f the fi al pr du t Th l l mat d de ati e l ll gh est tance t l i g By y the fre d l it ato tl pt m m t mpe at e q d f t g may l ed Tl therm etting mold ng c mp iti wh h h gl fil fill d a c t ly t wh l el t ely i ct e t rd a y t mpe at res Th mi t e i c l nked the h t d m ld l y th n e t al p r ce f r the m ett g mold g mp d

Polyethylene terephthalates Th m t p ly t wl h hav a h e ed g al mpo t n e e the p ly thyle t phth l t



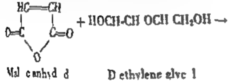
wh h y ld ry t g d l m lly t nt fib s d film P ly thyle te phtl al t the c p l g ed t f th p ly t file th t e a l ble in th nt y a d E p

Th pr pa t f th polym i l l t ps F t th d methyl d ethyle gl c l e t f t phth l d p d d a d lat d



Cross-linked resin

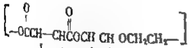
A l mol c la lt u at rated p lye ter mt med ate i f t p du ed The rea ti n f m l hydr d with diethyl ne glycol i typi al



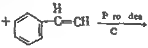
Unsaturated polyester

The p od ct a o oil f m le ul r weight f 2000–4000

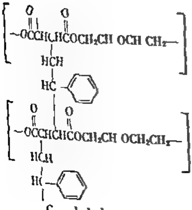
The l m l c l w ht u at r ted p lye t ll o f k th p se l p r d ly c p l me zat o w th sty r ther nyl nom Th t t d m l gro p op ly z e tially l l at o with tyr ne Therefore h sty mol le wh ch e t ffectiv ly j n tw e t l ns t th r to y ll a ol bl s-l k st ctur ch a



Unsaturated polyester



Styrene



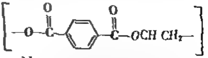
Cross-linked structure

The commercially available intermediate u tu rated polyester usually c nt n ab t 30% styrene r tl r nyl m n m r On add ti l per xide r other free-radical catalyst and a paint drier the op lym rizati tart In th tage the re may l h dled a i fl d f r a f w mi ite t a few l o d pend ng up n the act ity of the at ly t The r ou l q d may l applied t gla ll s (with a t ial urface t atm nt) in the f rm f m tt t w r ing r cl th with p ec ti n t elim nat air bubbl and to avoid l ibl le th t may be cau ed l y o erl e ting r lt of too rap l curing The rf ce f the gla fiber m t h e bee gi en a pec al fi hing tre tment n ad anc for the p lye ter to adhere tr ngly Cl f b r t ted with yl l c e or n o g o- cl me mpl are mmer lly a l l l

In th al of tl p i t dri r xyg f the a ha n inh l ting eff t n the cu ing pr ce with th e lt tl t the u face f the prod t r main ft after th in t l a h d ned l the pr nce f a paint drie u h col lt n phth te thi k ni g effect el m at d

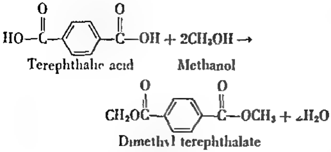
In e t je r a number f m dific t of the mp ti d sc b d al e h v been made Oth r d othe glyc ls l a mbi t m y be d t v ry pr pe t i h a fle ibil ty of the fin l p du t The hi in t d der t es h e h ghe t ce t b rn g By arying the f e r d al n t t r the pt m m temp atu e req i d f r ng m y b ar ed Th r are th m etting m ldi mpo ti n wh h h e gla fib a fill nd t ly t whi h r lat ly ins ti e t d n y t mpe t e Th mi tu c li k d n th h t d m ld by th nt nal p f r th rm ett g m ld ng omp und

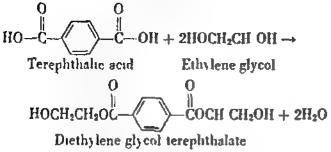
Polyethylene terephthalates The a matic p ly t s wh ch h v c l d g l mpo tance th p lyethylen t ephthalat



wh ch y ld v y t ng a d h m lly e tant fib a d film P ly thyl t phth lat the p t l ing d e t f the poly te fib th t e l l l i th o t nd E pe

Th p ep t n f th p lyme l e l t ps F t th dimethyl d ethyle gly ol t r f t phth l d p d d d l t d





Dimethyl terephthalate is then converted to polyethylene terephthalate through ester interchange by heating with ethylene glycol in the presence of a catalyst. Further heating under vacuum of the condensate eliminates the methyl alcohol and any excess ethylene glycol and low-molecular-weight polymers and results in the formation of high-molecular-weight amorphous polyethylene terephthalate. If the diethylene glycol ester is utilized instead of the dimethyl ester, further heating under vacuum yields the polymer with the elimination of the excess ethylene glycol.

Ethylene glycol is obtained by the oxidation of ethylene and terephthalic acid by the oxidation of p-dialkyl benzenes such as p-xylene or p-cymene.

As first produced, the polymer is usually amorphous, but it readily crystallizes on reheating or on extension of the spun filaments or cast or extruded sheet. Polyethylene orthophthalate does not crystallize readily nor does it yield useful fibers and film. Polyethylene terephthalate does crystallize readily and has the very high crystalline melting point of 249°C. *See* POLYMER PROPERTIES.

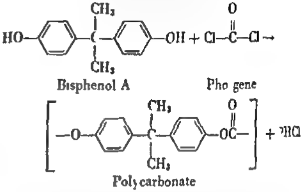
The fiber is resistant to mildew and moths. It is used frequently in combination with cotton for women's wear and men's shirts. Its chemical and heat resistance have placed it in demand for sails and cordage.

The film is tough, strong, and insensitive to moisture. It is used for special packaging, as photographic film, in electrical transformers and capacitors, and in high-strength laminates.

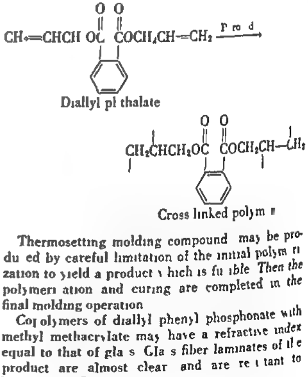
Aromatic polycarbonates. These are a strong, tough group of thermoplastic polymers formed most frequently from bisphenol A and phosgene. The products are distinguished by high softening temperature (usually greater than 140°C) and high impact resistance.

The reaction between bisphenol A and phosgene leads to the polycarbonate and the evolution of hydrogen chloride. Bisphenol A is obtained by the condensation of phenol and acetone, and phosgene is produced by the reaction of carbon monoxide with chlorine.

The polymer has recently become commercially available in this country as a molding compound. It is being recommended for electrical housings and as a replacement for metal in certain applications, such as die casting and brass and zinc bearings and bushings. Because it combines high impact strength and high softening temperature (for a thermoplastic), the product may be expected to grow into many applications.



Polydiallyl esters. These are polymers of diallyl esters, such as diallyl phthalate, diallyl carbonate, diallyl phenyl phosphonate, and diallyl succinate, in which cross-linked products are produced by polymerization of the allyl groups, as in the case of diallyl phthalate.



Thermosetting molding compounds may be produced by careful limitation of the initial polymerization to yield a product which is fusible. Then the polymerization and curing are completed in the final molding operation.

Copolymers of diallyl phenyl phosphonate with methyl methacrylate may have a refractive index equal to that of glass. Glass fiber laminates of the product are almost clear and are resistant to burning. *See* PLASTICS FABRICATION.

[J. A. M., L. M. H.]

Polyether resins

Thermoplastic materials which contain ether oxygen linkage, —C—O—C—, in the polymer chain. Depending upon the nature of the reactants and reaction conditions, polyethers with a wide range of properties may be prepared.

Three main groups of polyethers in use are (1) epoxy resins, prepared by the polymerization

f mat d epo y mpo d (2) p lyoxyeth ylne and p ly xyp opylene e s p lymer of eth l e a d pr p l ide re p ct ely and (3) pol ym thylene a h gh p lymer f f rmalde hyd Othe p lyethe obt d l y th etherif ti n of d ol a d p ly l uch as pe taerytl r t l are becom g a l bl S e POLYOXYETHYLATIO OF ALCOHOL.

Epoxy resins The p xy re f rm elati ely ew cl l r l ked p ly thers chara te i ed by ex elle t ch m al re t nce adh t gl nd metal l ctr l i lati g pr pert and a d p e f fab cati n

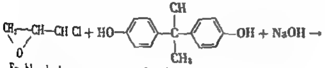
In th p r tio f the e pr du t a l w l ul ht d ep y mp nd i fi st m ed with cr h kin t fill a d pla t ci er and th n ff ed t e ther t r om tempe a t t w th the ppli t of he t

The t rmed te d ep xy mpo ds are co den t p d t of ep hl ohydri nd m t c d l nd a e s lable mmercially A ampl the p du t of th r cti of pichl o- h drin th b phe l A

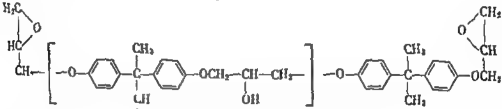
The type of cur g age t empl yed l a a marked eff ct n the ptimum t mpe ature of i g and ha me infl e n tl fi l l y i al pr pertie f tl e p d ct By ju lici electi n f the cur in y tem it po ible t carry t the curi g operati at alm t any temperature n tl ra ge 0- 00 C.

Vari s f ller su h as calc m carl nate m tal fib and p wder a d gla f l er are c mm nly ed in ep y f rm l tio rde t mpr e h p ope t a tl trength and resi ta t bra n and h gh tempe ature Fla ticizer ich s certa il a d re in may al be rp ted n epo y f rm l tion i rde t in ea e ela tic ty and d crea brittle e S me pl tic z uch mer ptans nd p ly mines l c me per man ntly l und t tl e p xy grou p and are u ally c lled fl ibil er

Be a e f the m ll d ity hange o cur ng d bec f tl ir ex elle t ele trical properti the epoxy re in a e u d a p tting r ncap ulat c mp n s f r th pr tecti n of del cate ele tr n emblie from the thermal d me-

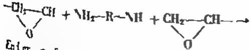


Ep hl hydrin B ph nol A S d um hydr de

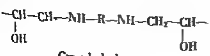


I t med t res

The l q d l d i t med ate bt ined e quite t bl but d t ha e ful phy cal p p rties unt l they p lym r d f th by th dd t n f a u er l nk ent n a m n im l r t dd ti n p lym t Poly n zatio m y b tiat d by cataly t h b on t fl d o t t ry m ns Alt t ely e mp d e t g t re hyd g n t m h g n a d l oh l me pt ns d p y d d ry m a l s rv t l y



End gr p f intermed t res n Am n c mpou d End gr p f t rmed at



Cro s l ked
(h h n t f rth th u h >NH —OH gr p)

h al h ck of ck t fl ght H u e f th ir d men l tab l ty and t ughn the ep x a e d t ely die f r t mp g metal f rm h s m m b le g h t k f m m t l h t g

P od t w th ten le st e gth ppr a h n tho e of t el c be m d u g fibr fill r Sh ts d yl d rs ta n ng poxy e i mbi t n with glas l th ha been p duced w th ten l st e th n th r ng f 00 000- 100 000 p

Th dhe e p p rt e f th s f r metal d the el t ely l gh st nce t be t a d to hem l ha e m d th epo y s f l f p ote ti c at f m t l a d for m tal to met l b nd g

Polyoxyolefin resins P lyoxyethyl n nd poly ypr pyl ne the m pl t p od cts who p op t gr tly fl ed by m lecul w ht d n th a e f p ly ypropyl n by the at f th p lyme izat n t ly t In gen al th p lym r l t ely t ble a they r p ep ed

$$n\underset{\diagdown\ \mathrm{O}\ \diagup}{CH_2\!-\!CH_2} \xrightarrow{\text{Catalyst}} [-CH_2-CH_2-O-]$$

Ethylene oxide — Polyoxyethylene

$$n\underset{\diagdown\ \mathrm{O}\ \diagup}{CH_2\!-\!CH}\!-\!CH_3 \xrightarrow{\text{Catalyst}} [-CH_2-\underset{CH_3}{\underset{|}{CH}}-O-]$$

Propylene oxide — Polyoxypropylene

Low to moderate molecular weight polyoxyethylenes vary in form from oils to waxlike solids. They are relatively nonvolatile, are soluble in a variety of solvents, and have found many uses as thickening agents, plasticizers, lubricants for textile fibers, and components of various sizing, coating, and cosmetic preparations. The polyoxypropylenes of similar molecular weight have somewhat similar properties but tend to be more oil soluble (hydrophobic) and less water soluble (hydrophilic).

Nonionic surface active agents can be prepared from C_{12}—C_{18} fatty alcohols and acids by the condensation of some 5–40 ethylene oxide groups, for example

$$C_{11}H_{23}COOH + 20\underset{\diagdown\ \mathrm{O}\ \diagup}{CH_2\!-\!CH_2} \xrightarrow{NaOH}$$

Lauric acid — Ethylene oxide

$$C_{11}H_{23}COO(CH_2CH_2O)_{20}H$$

A nonionic detergent

An interesting commercial example of a block copolymer has been produced by polymerization of propylene oxide onto polyoxyethylene to yield a linear chain with sequences of the two compounds

$$[-CH_2-CH_2O-]_x + y\underset{\diagdown\ \mathrm{O}\ \diagup}{CH_2\!-\!CH}CH_3 \rightarrow$$

Polyoxyethylene — Propylene oxide

$$[-CH_2-CH_2O-]_x-[-CH_2-\underset{CH_3}{\underset{|}{CH}}-O-]_y$$

in which x and y may be in the range 10–100. The hydrophobic-hydrophilic balance necessary for surface activity is achieved because the polyoxyethylene sequence is relatively hydrophilic and the polyoxypropylene sequence is relatively hydrophobic. *See* POLYMERIZATION.

Oil-water emulsions prepared by use of the product have remarkable stability to both hydrophilic and hydrophobic precipitating agents.

Solid high molecular weight, crystalline polymers of ethylene oxide and propylene oxide have been prepared by use of special catalysts. The polymer prepared from ethylene oxide in the presence of strontium carbonate is highly crystalline and melts at about 66 C. It is water soluble, resistant to oils and greases, and is recommended for thickening and sizing applications and for extruded or cast films.

Crystalline high molecular weight polyoxypropylenes with melting points up to about 74 C have been prepared with three groups of catalysts: (1) solid potassium, (2) complexes of ferric or stannic chloride with propylene oxide, and (3) certain metallic alkyls such as aluminum triethyl. By starting with optically active propylene oxide, an optically active polymer is produced.

Polyoxymethylene Polyoxymethylene has a high molecular weight and is a very tough and *strong thermoplastic material. The product has recently become commercially available and has*

$$n\overset{\displaystyle O}{\overset{\|}{HCH}} \xrightarrow{\text{Catalyst}} [-CH_2-O-]$$

Formaldehyde — Polyformaldehyde or polyoxymethylene

promise for diverse uses in molded and extruded articles because of its high strength and toughness and its chemical and electrical properties. *It is recommended for carburetor parts, oil-resistant electrical cable sheathing, pump impellers, and water sprinkler gears. The tendency of polyoxymethylene to depolymerize on heating has been eliminated in the commercial product, presumably by use of a polymerization system that yields inert end groups.* *See* EPOXIDATION; PLASTICS FABRICATION; POLYMER PROPERTIES. [J A M; L M H]

Polyethylene glycol

Water-soluble oily liquids and waxes of general formula $HO(CH_2CH_2O)_nH$. Their properties depend upon their molecular weights. Diethylene and triethylene glycols are used as dehydrating agents for natural gas, as textile lubricants, as humectants for glues and cork, and as starting material for the manufacture of plasticizers and explosives. The higher polyethylene glycols (up to a molecular weight of 800) are relatively nonvolatile liquids and find applications as heat transfer agents, lotion ingredients, and in the synthesis of nonionic surfactants. Solid polyethylene glycols are white crystalline products useful in pharmaceutical ointments, cosmetic creams, and rubber lubricants.

Polyethylene glycols with molecular weights up to 20,000 are manufactured by an alkaline-catalyzed reaction of ethylene glycol with varying amounts of ethylene oxide. *See* GLYCOL; POLYHYDROXY ALCOHOL. [J T A]

Polyfluoroolefin resin

A resin distinguished by resistance to heat and chemicals and by the ability to crystallize to a high degree. Two main products are the polymers of

$$\begin{array}{c} F\ \ F \\ |\ \ \ | \\ C{=}C \\ |\ \ \ | \\ F\ \ F \end{array} \qquad \text{and} \qquad \begin{array}{c} Cl\ \ F \\ |\ \ \ | \\ C{=}C \\ |\ \ \ | \\ F\ \ F \end{array}$$

Tetrafluoroethylene — *Monochlorotrifluoroethylene*

Copolymers of these monomers with various fluoro-

t fa includ n v nyl dene fluoride CH =CF and h x fl or pr pyl ne CF₂=CFCF are a ail able Fo a d pti f p ly inyl fl or de s e POLYVI YL RESINS.

Polytetrafluoroethylene T t afl o ethylene can be obta ned by the pyr lysis of m chlorod flu m thane hi h in tur i obta ned from a r th mplex react between nhydr u hydrogen flu de and chl form

$$CHCl_3 + HF \xrightarrow{SbCl_5}$$

Chl o- Anhyd o s
f rm h₂d fl ric
id

$$FCHCl_2 + F_2CHCl + CCl_3F_2 + HCl$$

$$FCHCl + AlCl \rightarrow F_2CHCl + CHCl_3$$

$$F_2\overset{H}{C}Cl \xrightarrow{700\text{-}800°C} F\,C{=}CF + 2HCl$$

Mon chlo
trifl m th n

Alth h p lyme zat on n b lk ca proce d with l e the m m c n be p lymer z d read ly a d o tly n mul n und pr ur sing f ee rad al atalyst uch as pe xid s or per ul f t Th p l me t oluble re sta t to heat and ch m l att ck d t add ti n has th low est oeffi t f fr ct of a y l d Bec e of n ta ce to he t th f b eat o f p lytet a fl th le eq m d ficat o of on en t l meth ds Aft m ld g th p wd d pol mer a old p e th mold ng are ntered at 360-400 C by pr c d s m l r to th e u ed a p d m t ll gy The tered p d ct c n be m h ned p hed Ext n po ibl if th p d comp nd d w th a lub ic t g m ter l liq co s sp n f th polym an l b ed f t g v arts l H we er pe al nt t tm t a e qu d to u e adh because polyt t afl or ethyl e do ot adhe well to ything

P l t t fluo oethyl n i us f l for ppl a t u d e t me d t of h at and hemi l t ty P lyt t fl o thyle l e eat pack g g k t a d tubi g n with t d rela t ely e e c nd t B c us f t ll nt t e l p p t e p lyt t fl o thyl n t l l wh n a l l t c m t l i r q ed f serv e t a h h t mpe atu Th n adhe q l ty a m t m be t n d to adv nt n th use f p lyt t aflu r ethyle t t r lls to h h m ter l might therw e adhere

Polymonochlorotrifluoroethylene The m n m p pa ed by th d chlo t f 1 1 2 tr hlo o-1,2,2 tr fl roeth

$$CCl_2FCClF_2 + Zn \xrightarrow{C_2H_5OH} CClF{=}CF + ZnCl_2$$

P l m izat a be r d ut n que u pe by the f e d l p in hich a b n f p ulf te a d b ulfite ed a th t

The pr pertie of p lym n ll trifl t r ethyl ene are generally imilar t t of polytetraflu oroethyle l we er the p e e c f the chlorine atom in t f me a t the p lym e t l littl l r tant t l e t a d t c l mi al The p ly m no hl tr flu r thyle n l e l ap l l y u e of con tional m ld ng and extr ion quipment d it i o l tai l in a tran par t n n ry talline cond tion by q enchi g D p ions f t e p lymer in organic m dia may l e u d for c ati g

The applicati n f polych l r trifl t r ethylen ar in g n ral imila t t e f r p lytetraflu roethylene Becau e f t tal lity a d ine ine the p lym r i ef l in t e m nuf ctu e f ga ket li i g nd val e ts that m t with tand l t and co ro iv nd t ns *Se* HALO ENATED HYDROCAR BON PLASTI S FABRICATIO POLYMERIZATION

[J A I L M H]

Polygon

A polyg of *n* de (> 2) is figure f med by jo n g n c der d t f *n* p i ts alled ert ces by l n egment called ide tl at c nne t ach p nt t t mmedi te c e (wl ere the fi t p nt s o d red tl u c r of the la t) Eu lid dered polyg n t b th figure and al th pl ne regi n b u ded by th e ert ces and de M der ag c nsiders tl p lyg n to be *ry set f lin* segm nts a d ert c f rmi g a l d b ke l n A polyg n i mpl l ea l de

( ) (b)

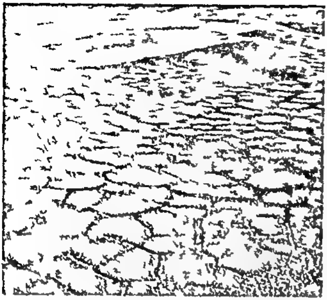
R gul p lyg ( ) P t g (b) He g n

i t rsect ly t two n ghb r It i pl ne o k w a rd g n de do do ot l pl ne A mpl pla p lygon c n ex if the polyg l r g n that i bo nd lie wholly n ne d f th (e te ded) l e of any d A p lygo of 3 4 5 6 7 8 10 12 d i called tria gl (3) q ad il te l (4) *p ntagon* (5) hexagon (6) hept g n (7) o t gon (8) de ag (10) *dode ag* (12) Th um of th ter o gl f ny co x p lygon 360 Th s m f the i t r o *angl* i (*n* − 2) 180 A c n ex polygon c ll d eg l f it h equ l a gl s nd equ l d S HEXAGON OCTAGON PENTAGON POLY TO ES REGULAR QUADRILATERAL SQUARE TRAPE OI TRIANGLE

[J S F]

Polygonal ground

A d mina t f rm f patt d gr d h *acter z* ng fr gm nt b r g g a elly and lty o ls n t eele s p l a d ubp l r i Altho gh p r t larly typ l f g o s of A t c pe mafro t,



A al obl q ▪ v ew ▪ er so l polygon north of Fa r banks Alaska (*MATS U S A Fo ce*)

polygonal ground is al o found in some high alpine areas of the middle latitudes Related ground pat terns in the e regions are tone circles nets steps and stripes In each orted (vell defined) and non sorted varieties are found The polygonal forms are the most triking and alwa occur in large groups never singly The most severe climate and greatest availability of water produce the most abundant large t and best sorted form The smalle t and least sorted types are found in le s evere and more arid fro t climates Under pre ent climatic condi tions polygonally patterned ground develops in areas where the mean ambient surface temperature is les than 10 C Where large relict forms exist outside of permafrost region imilar paleoclima tolo ical conditi ns are implied which may have bearing on Plei tocene history Such fo il forms in middle latitude u gest limits of frozen ground and permafrost a sociated with the climatological minima of the I e Age

The well sorted type of polygonal ground is the mo t wide pread The orted mate ial grades from silt and sand to gravel and angular rock fragment Sorted polygons have been ariously termed tone polygon tone ring Polygonenboden Typus I Steinnetz and other In the e the mesh is of dominantly polygonal form with the orted ap pearance re ulting fr m a border of stones outside of the fine material The e features range in ize from a few centimeters in diamete to 10 m or m re acro s Un orted forms are till polyg nal but with an ab ence of t ne borders Special names applied to this type are ▪ ure polyg ns mud polygons contractional polygon Polygon boden Polygonenb den Typus II Zellenboden and other designation

The origin of polygonal ground i not clear Whate er the proce s the pattern are created by the sy tematic egregation of coar e particles from the finer varietie in the urficial mantle A clue to the proce s in ol ed ome from the fact that the largest polygonal forms are found in fro t affected area mainly in the polar re ion One of the chief cau es eems to be local differential fro t heaving Other probable cau es of ortin are des sication as a re ult of aridity and contraction re sulting from extremely lo temperature A fur ther cau e appear to be cryo tatic movement through freezing induced hydro tatic pre ure which facilitates the transfer of fine to point of easie t relief In the mo t inten e developments it appear that a combination of the e eparate processes is respon ible for the trikin urface patterns which such ground di play *See* PERMA FRO T [M M M]

Bibliography A L Washburn Cla ification of patterned ground and review of su ested ori in *Bull Geol Soc Am* 67(7) 8?3–865 19?6 C Troll *Structure Soils Solifluction and Frost Climates of the Earth* U S Army Snow Ice and Permafro t Re earch Establi hment Corps of En gineers Tran lation 43 1958

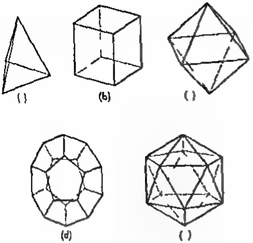
Polygonales

An order of the plant ubclass Dicotyledoneae hav ing one family (Polygonaceae) with 3? genera and 800 pecie mostly of the north temperate zone Usually the family is characterized by swollen nodes and a stipular grow th (ocrea) heathin the tem The fruit is a triangular ▪ lenticular achene In the order are many weedy plant and only a few species of economic importance Rhubarb or pie plant (*Rheum rhaponticum*) ▪ cultivated for it edible petiole *R officinale* is the medicinal rhu barb Prince s feather (*Polygonum orientale*) and coralvine (*Antigonum leptopus*) are grow n as orna mentals The ea grape (*Coccoloba uvifera*) of tropical beaches bears edible fruit Buckwheat (*Fagopyrum sa ittatum*) i cultivated a a food plant and is prized by the apiari t a a honey plant *See* BUCKWHEAT RHUBARB *see also* DICOTYLEDON EAE EMBRYOPHYTA PLANT KINGDOM [P D]

Polyhedron

A solid all f who e boundary p i ts lie in a fini e numbe of planes (at lea t four) The bo nd ng sections formed by the ▪ planes are plane polygo nal regions called faces of the polyhedron hose ide are called edge of the polyhedron and whose vertice are called ertices of the p lyhedron Ac co d ng as the number of faces i 4 5 6 8 12 or 20 a polyhedron i called a tetrahedron (4 face) pentahedron (5) hexahedr n (6) octahedron (8) dodecahed on (1?) ico ahedron (?0) For any convex polyhedron (but not for all polyh drons) the numbe of vertice V edge E and fa e F are related by the equation $V - E + F =$

Regular polyhedr ns are convex polyhedron who ▪ f ce are congr ent regular polyg n f rm ing equal dihedral angles at each edge If m reg lar n ided polyg ns meet at each ertex of uch a regular polyhedron then $mV = 2E = nF$ and the equat on $V + F = E +$ mpl es that $1/m + 1/n = 1/2 + 1/E$ Either m or n or both mu t



Th fi g l p lyh d ( ) T r h d (b) C b ( ) Oct h d (d) D d h d ( ) Ic hed

be 3 d th e ly fi e t g al l ts s f thi eq ti T h s lut e re po ds e f the fi egula l d lled pl to c lid f ll

\ m	m	}	E	F
Regul t t hedro	3	3	4	6	4
C l (regul h hedro)	3	4	8	1	6
R gul t hed	4	3	6	1	8
R gular dodecahedro	3	5	0	30	1
R gul cosahedro	5	3	1	30	0

The m dpo t f th fa e f reg l s l d t e rt m l the du l g l ol d ba ng *F* ru and f f ce R ta g l co d ate f r rt es f the fi e g l l d n b h e f ll h r $= (\sqrt{5} + 1)/2$

Regular t tr hed

$(1 1 1)\quad (1 -1 -1)\quad (-1 1 -1)\quad (-1 -1 1)$

Cube

$(\pm 1 \pm 1 \pm 1)$

R gula octahed

$(\pm 1 0 0)\quad (0 \pm 1 0)\quad (0 0 \pm 1)$

R gular h d

$(\pm \ \pm 1 0)\quad (0 \pm \ \pm 1)\quad (\pm 1 0 \pm \ )$

R gul d d c h d n

$(\pm \tau^2 \pm 1 0)\quad (0 \pm \tau^2 \pm 1)\quad (\pm 1 0 \pm \tau^2)\quad (\pm \ \pm \ \pm \ )$

S CUBE GEOMETRY EUCLIDEAN ; OCTAHEDRON P R LLELE IPE P LYTO ES EGULAR PRIS PR SM TOID A D P S OID PYRAM I A D F USTUM SOLID (EO IETRIC) TETR HED ON [J S]

Polyhydroxy alcohol

On f l f mp d w th mo th n e h d l g (—OH) h tt hed t p t bo t m of n l ph t k l t n Th gr p ncl des gly l gly l pe t yth t l d also h p od t s t m thyl l th t methyl lp p 1 2 6-h t l s rb t l t l d p ly ny l al h l

P lyol e btained from many pl nt a d an m l s ce and a e ynthe ized l y ariety of m thod 1 2 Glycol and glyc r l a pr du ed by the l droly f e de r chl r hydri F m aldehyde r ts with cet ldel yde pr p onaldehyd a d l tyraldehyde t f rm re p tively pe ta yth t l t imethyl leth ne and trimethyl olp pa Catalyt hydr genat n f s gars produce rb tol nd 1 2 6-hex netri l bt ined by the red tio of 2 hyd oxyad paldehyde Sap ni ficat n f p l yl a t te mpl yed in the in d t ial manufa t e f p lyvi yl lcoh l

$$\left(\begin{array}{c} \text{—CH—CH—} \\ \quad\ | \\ \quad\ \text{OH} \end{array} \right)$$

P ly l uch a glycer l pe tae yth it l t i m thyl l tha e nd trimethylolpr p e are u ed in mak n lkyd re ns for de r ti a d pr tec t e at g Gl ol glyce ol l 6-hex n tr l a d s bit l fi d appl cat n l i me ta ts and pl t izer fo gel ti gl e nd c rk Expl i e e m de by th it ti n f glyc l glycer l a d p tae ythr tol The fi t step in the manuf ct re of it mi C i l e th ferme tat e x dati n f b tol t so bo e In t l

$$\underline{\text{CHOH—CHOH—CHOH—CHOH—CHOH—CHOH}}$$

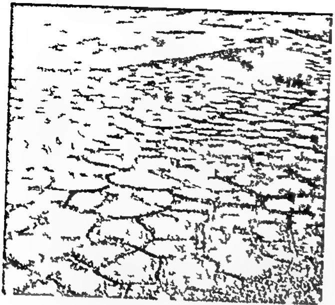
l d t i m y pla t a d ca be ester fied w th ph phor cid t f rm i o t l he aph ph te (phyti d) wh ch i u ed i med ci e a th cal i m m g si m alt *S* ALCOHOL GLYCEROL GLYCOL PE TAERYTHRITOL. [J T A]

Polymastigida

An orde f th cl Zo ma t g ph e Thi or d als kn w a P lyma tig n n l de d er g m ngly l ely lated m ph l g lly c s der bl di sty f p n to t xo m tat s f ome r p e entat e t P G a e ba d th der Gene lly they re d py f rm l te 5–350 μ l g l l with thi p ll l d pl st c S m ha e yt t me nd me h nd lat memb b d ed by t a l ng fl gell Ma y ha e t r t m b ht d wh ch th (*D ll g i*) (F l) t ma y (*C l myph*) fl g lla em g Symm try bil t al wh h s met m b d by d y d l mm t b t ne g up p se do bl et f g lle i cl d le a m r h l Flag ll r s fr m d d l f ed bl ph pla t fi ted t pa b al mpl x n t d with cl e t te n l b th f q ntly a o t d w th tyl t fl r dl k o t

Th e t le t 10 f e-l f h w t m e g th em de e p r t c m m l D pt d t m ew th d f d H l g l mp t nc

Th t rmt dw ll g *T h ymph* pl ed n th Hyp m t g d b R K d s b ll h ped yl ph g rg m wh h l ks a d fi t



Aerial oblique view of sorted soil polygons north of Fairbanks, Alaska (MATS, U.S.A.F. photo)

polygonal ground is also found in some high alpine areas of the middle latitudes. Related ground patterns in these regions are stone circles, nets, steps, and stripes. In each, sorted (well defined) and nonsorted varieties are found. The polygonal forms are the most striking and always occur in large groups, never singly. The most severe climate and greatest availability of water produce the most abundant, largest, and best sorted forms. The smallest and least sorted types are found in less severe and more arid frost climates. Under present climatic conditions polygonally patterned ground develops in areas where the mean ambient surface temperature is less than 10 C. Where large relict forms exist outside of permafrost regions, similar paleoclimatological conditions are implied which may have bearing on Pleistocene history. Such fossil forms in middle latitudes suggest limits of frozen ground and permafrost associated with the climatological minima of the Ice Age.

The well sorted type of polygonal ground is the most widespread. The sorted material grades from silt and sand to gravel and angular rock fragments. Sorted polygons have been variously termed stone polygons, stone rings, Polygonenboden Typus I, Steinnetz, and others. In these the mesh is of dominantly polygonal form with the sorted appearance resulting from a border of stones outside of the fine material. These features range in size from a few centimeters in diameter to 10 m or more across. Unsorted forms are still polygonal but with an absence of stone borders. Special names applied to this type are fissure polygons, mud polygons, contractional polygons, Polygonboden, Polygonenboden Typus II, Zellenboden, and other designations.

The origin of polygonal ground is not clear. Whatever the processes, the patterns are created by the systematic segregation of coarse particles from the finer varieties in the surficial mantle. A clue to the processes involved comes from the fact that the larger polygonal forms are found in frost affected areas mainly in the polar region. One of the chief causes seems to be local differential frost heaving. Other probable causes of sorting are desiccation as a result of aridity and contraction resulting from extremely low temperature. A further cause appears to be cryostatic movement through freezing-induced hydrostatic pressure which facilitates the transfer of fines to points of easiest relief. In the most intense development it appears that a combination of these separate processes is responsible for the striking surface patterns which such ground displays. See PERMAFROST. [M.M.M.]

Bibliography. A. L. Washburn, Classification of patterned ground and review of suggested origins, *Bull. Geol. Soc. Am.*, 67(7):823–865, 1956; C. Troll, *Structure Soils, Solifluction, and Frost Climates of the Earth*, U.S. Army Snow, Ice and Permafrost Research Establishment, Corps of Engineers Translation 43, 1958.

Polygonales

An order of the plant subclass Dicotyledoneae having one family (Polygonaceae) with 32 genera and 800 species, mostly of the north temperate zone. Usually the family is characterized by swollen nodes and a stipular growth (ocrea) sheathing the stem. The fruit is a triangular or lenticular achene. In the order are many weedy plants and only a few species of economic importance. Rhubarb or pieplant (*Rheum rhaponticum*) is cultivated for its edible petioles. *R. officinale* is the medicinal rhubarb. Prince's feather (*Polygonum orientale*) and coralvine (*Antigonum leptopus*) are grown as ornamentals. The sea grape (*Coccoloba uvifera*) of tropical beaches bears edible fruit. Buckwheat (*Fagopyrum sagittatum*) is cultivated as a food plant and is prized by the apiarist as a honey plant. See BUCKWHEAT; RHUBARB; see also DICOTYLEDONEAE; EMBRYOPHYTA; PLANT KINGDOM. [P.D.]

Polyhedron

A solid all of whose boundary points lie in a finite number of planes (at least four). The bounding sections formed by these planes are plane polygonal regions called faces of the polyhedron, whose sides are called edges of the polyhedron and whose vertices are called vertices of the polyhedron. According as the number of faces is 4, 5, 6, 8, 12, or 20, a polyhedron is called a tetrahedron (4 faces), pentahedron (5), hexahedron (6), octahedron (8), dodecahedron (12), icosahedron (20). For any convex polyhedron (but not for all polyhedrons) the numbers of vertices V, edges E, and faces F are related by the equation $V - E + F = 2$.

Regular polyhedrons are convex polyhedrons whose faces are congruent regular polygons forming equal dihedral angles at each edge. If m regular n-sided polygons meet at each vertex of such a regular polyhedron, then $mV = 2E = nF$ and the equation $V + F = E + 2$ implies that $1/m + 1/n = 1/2 + 1/E$. Either m or n or both must

ganic ompl tely in rg nic p lymers These t est ha e emph zed the need for further u rsta ding of the principles f alence int rmo cular att ti fo ce a d the pr pert es of y tal nd the hetero eneitie d persed r n pho mat es *See* PLASTICS FABRICATION

[J A M L M H]

B bl g aphy P J Fl ry *Pri ciples of P ly Ch mist y* 1953 *Mode n Pl st s E cy lop a* 1960 W J R ff *F b rs Pla tics a d R b* 1956 A X Schm dt and C A M rlie *P i ples of H gh P lym r Theo y d P act ce* 1948

olymer properties

he pr p rti s f p lyme m t r als wh ch re eterm ed by the m le la pr pe t es of the ma m lec les, the type f form latio in l g d st ize s or fillers the c nd tion of f brication wh h m le la tation r c y tall zati n y be ind d P p t l o depe d the tem t a d l p ed time f th me urement

Molecular properties The e lud mole ul r ze a d ght, m l l r str ct re or arch tec ur molecular w ht d t b t n p lar ty nd l bl ty f th p lym ic ch s (o chain eg ts betw en s links c d or lean ed polymers) M l lar properties t ken t gether d t rmine the tt ti f r e betwe the m le cules d the g e al b h v of the p lyme

M l c l ght a d dist ib t on The de bl pr p rties of hi h polym (t ngth d re t n e t s l t) n r e p dly with s e s g m lec l w ght n th l w g of m l l ght, nd m lowly the h gh ang O th ther h nd th m lt v ty re se with m lec l r w ght in th opp t m r slowly at fir t d r p dly the h gh m l lar w ght r ge The f fab cati (m ld g e t n a d h p ng) f p lym ic mp t a ie n ly w th th m lt ity th t the m t n l be me gly d ffi ult t m ld trud at ery h gh al of m lecula we ght Th pt m m m l l r we ght of p lym f q tly a es f r d ff ent ppl at n nd d ff t m th od of f b c t n C mm c l p d t r us lly l bl e l m l l w ght ra ge h we the pt m m m l l e ght m t b l ct d the b f th be t mp m se f r d s ble pr p rt e d e f f bri t T h q f mea g m l c l p pert a d meth ds f f b t n a b efly d sc sed at th nd f th a t le

Th m l ul w ght d t b t pr t the p rt la c mb n t of mat ial f l w m d m a d h gh m l l w ght a g e p d t Th pres f l w m l ul w ght p t m y lo th ft g temp t ge f th p d u t, m k t m e s bj ct to tta k by l e ts a d h m cal g t d l w th m lt c ty cr se th f f bri t The l w m l ght p rt b ha e m le s pla t ze Th p e c f v y h gh m l l w ght port a es th m lt ty b t doe n t h pr ed ff t

Frequently tl e ery h gh molecula weight por tions re ct ally in oluble bei g highly branched o cro s-l ked The in luble port n sh w p as fi h-eye n film and d c tin iti in fibers a d they gi e u des ral le nerve (ela t m m ry) cha act ri t cs t c mp unded n ured rubber

Att ctive forc s The atom in the ch n are h ld t gether by prim ry ale ce bond If it were po ble t apply a f rce f te sion only to the pri ma y alen b nd then a ten ile strength of m re than 2 000 000 p i w uld be b rved In r al ty h wever der te ion the mole les lip pa t ne another and the re istance to th at sl ppag is due t th eff cti e att act e f rces (van der Wa ls fo ces) between the molec les *See* CHEMI CAL BI DING

The ffe ti e ttr ti e force a e the re ult of the pol ity f the gro p i or attach d to the cha ns and of the d gree f fit betw n ch i Str gly pola g o ps ch a th e conta g yge nitr gen and lfu and oth r pol at m ct the t ge t attr ti e f rce B lky d g oup att hed t the m n ch i tiffen the ch i s d al by the r b lk m y pre ent l e fit betwee ha

How er f the b lky de gr ps are ar a ged n a te e egular w y (as i tactic p lymers) then l e fit is p s ble nd cry tall ation m y a

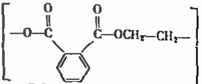
An mple f the strong att tion of polar g ps is f nd n the c mp ri n f th p pert es f p lyam de and N m thyl p lyamides

$$\left(-\overset{\text{O}}{\overset{\|}{\text{C}}}-\overset{\text{H}}{\overset{|}{\text{N}}}-(\text{CH}_2)_5-\right) \qquad \left(-\overset{\text{O}}{\overset{\|}{\text{C}}}-\overset{\text{CH}_3}{\overset{|}{\text{N}}}-(\text{CH}_2)_5-\right)$$

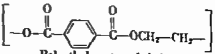
Nylo 6 N Methyl nylon-6

Nyl n 6 relat ly high melt ng hard st g d i luble wh the N methyl de t is l w r m lt les t ng a d m r dily s l The t oth f th hyd g n b d between the >N—H g p and th o yg at m f n adja ent h n s m 10 k l/m l By repl g the >N—H by >N—CH th t molec l att a t e f are d d t p h ps 2 3 kc l/m le

F r An x mpl f th ff t f th r gul rity f ch n the fit betw th m i se th m p of th p p t f p ly thylen o tho- phth l t d p ly thyl te phthal t



P ly thyl n o th phthal t



Poly thyle e t phth l te

Th pa d i t ly thyl phth l t

axostyle and parabasal body. Its nucleus is centrally located and many flagella occur in longitudinal rows down the bell sides. Wood is ingested posteriorly. L. Cleveland described its complicated sexual processes.

Trichomonas buccalis, *T. hominis*, and *T. vaginalis* (Fig. 2) inhabit respectively the mouth, colon, and vagina of human beings. Some workers believe all are one species but differ on whether they cause disease. *Tritrichomonas* (*Trichomonas*)

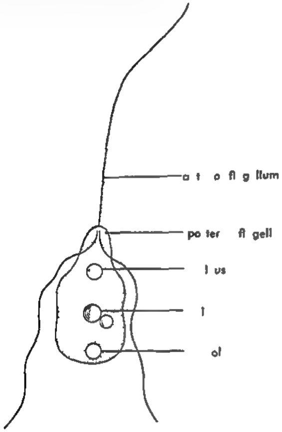


Fig. 1. *Dallingeria drysdali.*

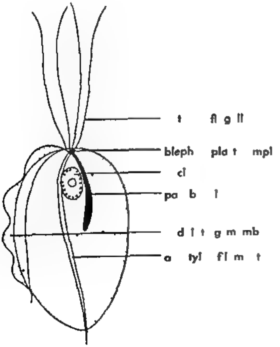


Fig. 2. *Trichomonas foetus.*

foetus causes abortion (Bang's disease) in cattle, and *Chilomastix mesnili* is a commensal in the human colon, eating bacteria. *Giardia* (*Lamblia*) *intestinalis* occurs in the human intestinal tract. In certain cases of human diarrhea it has been recovered, with the implication that it may be the causative organism. The condition is known as giardiasis. *See* ZOOMASTIGOPHOREA. [J.B.L.]

Polymer

The terms polymers, high polymers, macromolecules, and giant molecules are used to designate high-molecular-weight materials. Resin refers to an uncompounded macromolecule. Plastic, rubber, fiber, and coatings refer to formulations of polymer with other ingredients such as filler, pigment, plasticizer, and age stabilizers.

For a discussion of the general methods of preparation, catalytic processes, and the effects of the conditions of polymerization upon the molecular weight and molecular structure or architecture of the polymeric product, *see* POLYMERIZATION. For a discussion of the effect of molecular weight, molecular structure, and the conditions of fabrication upon final properties, *see* POLYMER PROPERTIES. For descriptions of typical synthetic polymers of the condensation type, *see* AMINO RESINS; CELLULOSE DERIVATIVES; PHENOL-FORMALDEHYDE RESIN; POLYAMIDE RESIN; POLYESTER RESINS; POLYETHER RESINS; POLYSULFIDE RESIN; POLYURETHANE RESINS; SILICONE RESINS; UREA-FORMALDEHYDE-TYPE RESINS. For descriptions of some important members of the addition-type synthetic polymers, *see* HYDROCARBON RESIN; POLYACRYLATE RESIN; POLYACRYLONITRILE RESIN; POLYFLUOROOLEFIN RESIN; POLYOLEFIN RESINS; POLYSTYRENE RESIN; POLYVINYL RESINS.

Natural products, rubbers, fibers, and paints are treated in other articles. Biological polymers such as enzymes and living tissues are treated in the appropriate articles. *See* CELLULOSE; FIBER, MAN-MADE; FIBER, NATURAL; PROTEIN; RUBBER; SURFACE COATING; TERPENE.

The first modified natural polymers, cellulose nitrate and casein formaldehyde, were commercially produced about 1860, and the first fully synthetic polymer, phenol formaldehyde, was made about 1910. The major development of present polymer science and technology has taken place since about 1920, while the production of polymeric material in the United States has grown from a few million pounds to several billion pounds in the same time period.

Interest in the synthesis of products similar to natural products but possessing more useful properties has been continually stimulated by the successful synthesis of polyamide fibers and a rubber equivalent to natural rubber, and by increasing understanding of the nature of protein, carbohydrates, and enzymes in living tissue. The need for polymeric materials which can be easily shaped, which possess high resistance to heat and to chemicals, and which have high strength has initiated a rapidly growing interest in inorganic

R ll m ll gma bl de a d d gh m e e gen ally employed to m x the resin w th pl t ers a d p gm t t mod tely ele ated t mp t e 50-11 C.

Add t The add t f pl tici t poly n m t l u e it to b fte and m ul bery h racter Pl t c e are h ld in a t n ith the p lyme cha by ec d y ale e f rce Th y epar t the m lec le and the eby red th eff t e i termolec l attr t e f es.

F n lv d ded p l r ubstan may t a strength fill s f pl t c Th fill f es d b l nks of everal polyme chain a d p od e the ffe t f l k ng F lled pol m n e mp ti are freq tly harde tr ge m r t nt t ab n d l la n th n the nfilled pr duct Th effe t of t fib r fill (gl s l or othe mat al) n the ten l propert e f e al polyme s mp es e Pr d t with te le t e gths f 50 000–100 000 p b obta ed

Ag i h b t r a e lmo t lway t p ted i p l m mpo t O yge oz e l ght d l t c d ha g p d i e f ee ad ls wh h d dat f the p l mer hai F e r d al h b t r d l ght masking agent ar ther f mm ly ed *S* INHIBI OR (CHEMI CAL)

P l bl ds I c mpl ti d cu f th ef fect of m l la e ment ch r te t fi al p pert f p lyme m t h ld be m d f th t n h cter ti f p lyble d B th dd t f mall m nt f a ubbery p lyme t p l m c gl th mp ct t gth f th latter b t t lly i c d Th bbery p ly m t t ly mpatibl d ex t fi ely d p ed p rate ph e The ph men n h m e h t m l nte p rt i rg e gl tech l gy d n phys c l m tallu gy The t dy f polybl d dem t ate the gr w g nt t i th old t t phy a d phy l m t ll oy f m m lec le

Fabricat on. P l me f m l t b f b i t d int sef l f m o t le by a ty f ethod

I the f m ld d the m ett mpo t n h h h t d p e s r req d f the p od t n f d t l m f m f m P n m ld g s mpl v d Th phy lly p t d mp t tai g th e the f ff t f d i t m ld ty f th de ed h p d h ld d r he t nd p s the n g l t i mplete Wh n h b p e not d th p t n I poxy mp t p lyest ty gla fib compo d a d f t c g r si l m tes t t ll d bl t m d te p e t f f m m ld f m f inje t m ld n u d f r th h p g f th m pla ti (pe m ntly f mpo Th mp t fi t ft ed tempo ly by f g th mp ded e a lesth gh h

s dri n i to a r lati ly cold m ld Under proper c ditio tl e r in rem ins ft l ng nough t fill the m ld completely d th rapidly harden as it cool Var at ns f th jecti mold ng p oc a e u d in tl e e t ion f film rods and p pe and the p ning f fil ers

Film e al o prod ced by e tru f a tube into wh ch air i f ced The p o e i c lled bub ble e t u i Th pipe expand I ec u e f th air p sur t a wall th ck s eq ivalent to the film thi kne s de i ed Tl e wall of the e pa ded bul ble ar pr ed t geth in nip r ll and later the l ge th n w ll d coll psed pip is lit to y ld flat film Films and heets a e al prod ced by cale de i g i whi h the hot re is for ed be tw en t htly fitted r ll

I th ca t ng p s fluid compo tio are poured t m ld of th de ed hape nd then all wed to l ct re This pr i ed f the p od ction of fo ms nd in en p ulat on such a in the p te t on f elect n c c mp n t r the m nt g f biol gi l p mens In br d terms oat g lush moldi g nd pa nting may be n dered to be c sti g oper tions

In the hap ng f therm pl t c p rti la ly the ndit n of molding (t mp atur t me and pr su) h e a ma ked effect o the pr pe ties f the fi l p od ct Une e o li g p od es tr i s nd th fl w f th pl t cized re in c n ca s me e t ti f the m le l In l i bbl mold g f film b ax l te tat n prod c d In th d awn of film a d fibe nia al te tation re s lts lth ugh films m y l e p tially tr t h d w th qu pm t m l r t the Te ter f ames of the t t l d try O e tat r ults a si bstan t al a e i the st e gth of the pr d ct in th d rect f t et h g ma y p lym ys- t ll z t on i d ed d r ng ld dr w g t et h g On c i n di onti uit es reas f t ain e p od d by p rt ally r enti the mol ules nd th p odu t b c m s m r ubj ct to t s k n the p n e f ol ent r other g nt Th s the ptimum nd t n f d t It f m j d o mb t f me h n l t tm nt d therm l a n l *S* PLASTICS FABRICATION

Measurement of molecular properties Beca s f th d m t t st cal t r f the p lyme t n p e d t ib t of h le gths th t m l la we ht lways f med d m s- ed m l la we gl ts re n ily g l B f the e y high m l c l we ght f m m le le the mm n m th d l m g p p t f ol t s (f e mple th f g p t l we i g) e f q tly n t sui t ble Amo g th lligat e m th d th m t p e d t mo t ef l nd g es um b r ge m le la w ght l e o ble r y p t b t 500 000 Th b l g p t el t m th d t ble f m l l r w ht to 5 000–10 000

The f t th t th m t f l ht att d by l t s a f t n f th m l la w ght of

temperatures crystallizes more readily and is stronger and less soluble than the other polymer Although the chemical nature and polarity of the two polymers are identical the effective intermolecular attractive forces between adjacent chains are greater for the para product because its structure allows a closer interchain fit

Crystallinity When a close fit between chains is possible crystallization can take place spontaneously or by drawing or cooling The crystals represent a configuration of minimum distance between molecules Because the long threadlike coiled and entangled chains are never fully untangled even on drawing crystallization never reaches completion Crystalline polymers may contain up to 90–95% crystallinity with the crystals embedded in and exercising an effect upon the remaining amorphous polymer The behavior of a partially crystalline polymer is somewhat like that of an amorphous polymer containing a finely dispersed filler or strengthening pigment and for rapid stresses it is somewhat like that of a chemically cross linked product

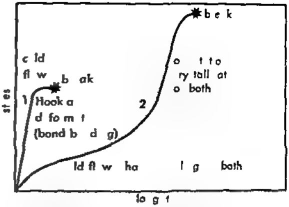
Amorphous products which are strongly oriented by cold drawing but which are not thereby crystallized show evidence of closer fit between chains by increased strength in the direction of stretching

Flexibility The flexibility of linear polymer chains and of the segments between cross links in cured products is decreased by the presence of polar groups and regularity in the molecular structure A nonpolar irregular chain should be the most flexible Products containing highly flexible chains are rubbery soft and nonbrittle with relatively high resistance to impact and to tear

The limited type of Brownian motion that is possible in polymer chains and the effective attractive forces between chains are highly temperature dependent If the temperature is increased the rubbery qualities increase The second order transition temperature or glass point is in somewhat arbitrary terms that temperature below which the chain segments are relatively immobile and the product has glasslike properties being brittle and hard The first order transition temperature is the crystalline melting point Above the glass point the chain segments have relatively high Brownian motion and the product is leathery to rubbery Thus with variation of temperature and treatment many polymers may exist as rubbers or gums hard glassy solids which may be partially crystalline or strong fibers and films which are frequently highly crystalline and have high softening points

Behavior under stress The illustration indicates the type of stress elongation behavior shown by a typical glassy or crystalline polymer and a typical rubber or amorphous polymer capable of strengthening or crystallization on orientation

The nature of the properties depends also upon the elapsed time of the measurement In high speed vibration rubber is stiff and acts more like a plastic glass Under long term tension some glasslike plastics will simply flow as liquids



Stress-elongation behavior of polymers Curve 1 glassy or crystalline polymer Curve 2 rubber or amorphous polymer

The cross linked polymers are usually substantially stronger than corresponding linear products however their strengths fall far short of the hypothetical 2 000 000 psi Linear polymers break by overcoming the intermolecular attractive forces and possibly to some extent by the rupture of primary bonds Cross linked polymers break by the latter process In both cases the break probably starts at a fault in the sample

Elasticity There is a profound difference in the elasticity of rubbers of hard brittle plastics and of strong partially crystalline fibers When rubber is stretched the flexible coiling segments between the cross links are straightened On release of the stretching tension the segments resume their random coiling condition An increase in temperature increases the freedom of the segment to seek their random condition and thereby increases the restoring force for a particular elongation In crystalline solids and in polymeric glasses and fibers at temperatures below their glass points the elasticity of the Hookean type is small and is due to the bending of bonds On increasing the temperature the restoring force is lessened On extension of polymeric materials both rubberlike and Hookean elasticity may be present and there may be some cold flow or permanent slippage of the molecules On release of the external force there may be an immediate recovery of the Hookean deformation and some of the rubberlike deformation a slow recovery of some of the rubberlike deformation (in cases in which free coiling and uncoiling of the segments is impeded by polar groups) and nonrecovery of the deformation due to slippage of the molecules or cold flow

The term elastic memory applies to cases in which a polymer is deformed at an elevated temperature as in shaping of a sheet into a dome and then is cooled before the tangled chains have reached an equilibrium condition in the new shape Strains are said to be frozen in and at a later time especially if the product is warmed these strains will cause the product to assume a distorted shape

Compounding Plastic masses rubber formulations coatings and other polymeric compositions may contain age inhibitors strengthening and coloring pigments and plasticizing or softening agents

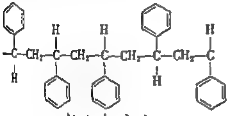
A—A—A—A—B—B—B—B—B

Block c polym

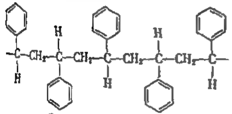
A—A—A—A—A
|
B
|
B
|
B

G aft p lym

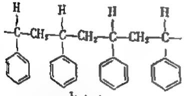
Isot tic syndy ta t c t oreg lar poly mers a formed in the p enc f c mplex cata lyst The gro ps tta hed t the chai i ter result p lymer a e a ra ged n an ordered m



Atact (andom)



Syndy tact c (alte t)



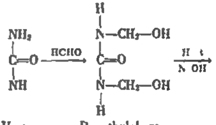
Is ta t c

The gul t t s of th is ta t a d yndy tac ic form m k them p bl f cry t ll zati n The cr stall e m lt po t f i ot tic p ly mers e ub t t lly h ghe th n the fte ing p nt of th t t c p d ct Th p d tio f cis poly p ene ynth t n t l rubb Is n ex mpl f t eg l r polym r t

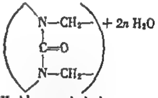
CONDENSATION POLYMERIZATION

Th f mat f m mol ul s by the n den tio pro a the p d ct n of p ly a des polyest d p lysulfid q i s th m tio f m ll m l l s ted b e at th sam t me tr gl p l a d tr gly ttr t ing g ps e p d d I th q m l act f a d bo yl ac d w th d m e n m T after 50% f th gr ps h re t d the a r e d gree f polym r zat n (DP) f th p lym form f 2 a ter 90% r t th DP 10 d f 99.5% e t th DP i 200 If th m l lar weight of the repeati g n t m 100 then the a erage m lecular wei ht of the p lymer is 20 000 In order to obta a h gh molecular weight prod uct the small mole ules f rmed d ring the c nden t on m t b r mo ed in der f r the eact on t approa h 100% completio In p acti the con den tions a e u ally tarted under m derate con d t on f temperat re a d pre ure and completed *t h gh temper t re a d l w press ire* to yield l ear produ ts in the molec lar weight range of ab t 5 000-30 000 The l ne product thermo-pla t c a d cond nsat on resins are ed in fibers film d coating and n m lding c mpo d and adhesi s

U eful ond sation p lyme s which are highly l nked ar prepared f m low molecular weight p lyf ncti al r act n systems Th con dens tion of f maldehyde w th ph ol and with u ea an l the c ndensat f phth l c nhydride with glyc l nd others are d cus ed in the rt cl s on spe ific p du ts The r action of formalde-hyde with rea will erve as n e ample



U ea D m thylol re (t trafun t al)



H hly c ss l ked ur a f rmaldehyd r s n (n ol bl nf s bl)

I the termed te c mp u d d meth l l u is tet af n ti al Th H— nd HO— gro ps n one m le l react w th th HO— d H— oups th mol le t f m water Ea h ure nit fi n lly become b nd t th r rea un ts a f ur m thyle (—CH₂—) bridg s Bec e th fi al p d t r s l ked a d inf ble th final hap- t mu t co n d w th the fi l cu ng o l k g I pr ct the l ble l w m l cu la w ight t rm d ate co d n ate c ld b so-*lated nd m x d w th st ngth g fille s c l* g p gme t nd ng t lyst t y eld a m ld g p wd By ubje t g th re f mald hyde m ld g p wd t h at and p es u i mold the ng e t o t kes pl c om f the w te d e fi t m nd m i adso b d by the *fill r Th m ld d obje t,* h d c bin t r l mp h de s ow lubl nd i f bl B au ll the m lecule j d t gether th m le l we ght f a h ghly l ked

the determination of weight average molecular weights up to several million The light scattering measurement can also yield valuable information regarding the shape of the molecule in solution

The determination of molecular weight and also molecular weight distribution can be accomplished by use of the ultracentrifuge in which the rates of settling of particles in intense centrifugal fields are measured

The intrinsic viscosity of a polymer in solution (the viscosity which the unassociated polymer molecule give to the solution) is a function of the molecular weight and is very easily measured Intrinsic viscosity is commonly used for control purposes and the values can be converted into molecular weight by calibration with osmotic pressure light scattering or sedimentation molecular weight measurements

The second order transition temperature is a time-dependent function Normally it is measured by noting the temperature at which the slope of a flexibility temperature curve changes abruptly *See* COLLOID FIBER MAN MADE POLYMER POLYMERIZATION SCATTERING (ELECTROMAGNETIC RADIATION) ULTRACENTRIFUGE [J A M L M H]

Polymera

A division of the phylum Vermes proposed by O Butschli in 1910 with the rank of a subphylum The Polymera are equivalent to the phylum Annelida The Amera and Oligomera are the other subdivisions of the Vermes which were recognized *See* AMERA OLIGOMERA [C B C]

Polymerization

The linking of small molecules (monomers) to make larger molecules Polymerization requires that each small molecule have at least two reaction points or functional groups There are two distinct types of polymerization processes the condensation polymerization in which the chain growth is accompanied by elimination of small molecules such as H_2O or CH_3OH and addition polymerization in which the polymer is formed without the loss of other materials

An example of the condensation process is the reaction of ε aminocaproic acid in the presence of a catalyst to form the polyamide nylon 6

$$n\mathrm{H_2N{-}(CH_2)_5{-}\overset{\displaystyle O}{\overset{\|}{C}}{-}OH} \xrightarrow{\text{Catalyst}}$$

ε Aminocaproic acid

$$\mathrm{H}\left[\mathrm{-\overset{\displaystyle H}{\overset{|}{N}}-(CH_2)_5-\overset{\displaystyle O}{\overset{\|}{C}}-}\right]\mathrm{OH} + (n-1)\mathrm{H_2O}$$

Polyamide nylon 6

The repeating structural unit is equivalent to the starting material minus H and OH the elements of water A similar product would be obtained by the reaction of a diamine and a dicarboxylic acid In both cases the molecules formed are linear because the total functionality of the reaction system

$$n\mathrm{H_2N{-}(CH_2)_6{-}NH_2}$$

Hexamethylene diamine

$$+\ n\mathrm{HO{-}\overset{\displaystyle O}{\overset{\|}{C}}{-}(CH_2)_4{-}\overset{\displaystyle O}{\overset{\|}{C}}{-}OH} \rightarrow$$

Adipic acid

$$\mathrm{H}\left[\mathrm{-\overset{\displaystyle H}{\overset{|}{N}}-(CH_2)_6-\overset{\displaystyle H}{\overset{|}{N}}-\overset{\displaystyle O}{\overset{\|}{C}}-(CH_2)_4-\overset{\displaystyle O}{\overset{\|}{C}}-}\right]\mathrm{OH}$$

Polyamide nylon 6 6

$$+ (2n-1)\mathrm{H_2O}$$

(functional groups per molecule) is always two However if a trifunctional material such as a tricarboxylic acid were added to the nylon 6 6 polymerizing mixture a branched polymeric structure would result because two of the carboxylic group would participate in one polymer chain and the third carboxylic group would start the growth of another At high conversion these chains could become bridges between linear chains and the polymer would then be cross linked

Some examples of addition polymerization are

Linear polymer chain branched polymer chain cross linked polymer chain

$$n\mathrm{H_2C{=}O} \xrightarrow[\text{Initiator (I)}]{\text{Catalyst}} [\mathrm{-CH_2{-}O-}]$$

Formaldehyde → Polyoxymethylene

$$n\mathrm{CH_2{=}CH_2} \xrightarrow[\text{Initiator (I)}]{\text{Catalyst}} [\mathrm{-CH_2{-}CH_2-}]$$

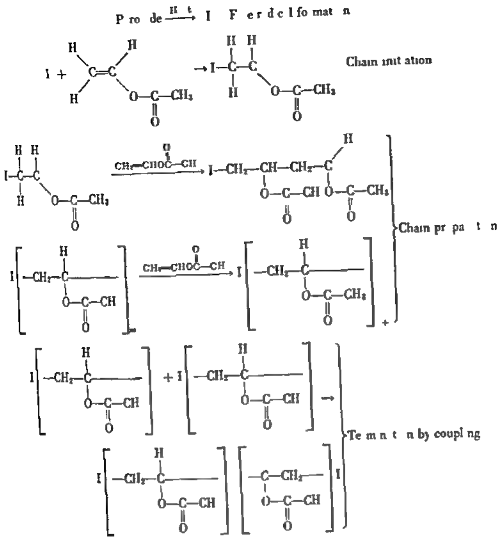
Ethylene → Polyethylene

The structure of the repeating unit is the difunctional mer In the presence of catalyst or initiators the monomer yields a polymer by the joining together of n mer links If n is a small number 2–10 the products are dimers trimers tetramers or oligomers and the materials are usually gases liquids oils or brittle solids In most solid polymers n has values ranging from a few score to several hundred thousand and the corresponding molecular weights range from a few thousand to several million The end groups of these two examples of addition polymers are shown to be fragments of the initiator

If only one monomer is polymerized the product is called a homopolymer The polymerization of a mixture of two monomers of about equal reactivity lead to the formation of a copolymer a polymer in which the two types of mer units have entered the chain in a random fashion If chains of one homopolymer are chemically joined to chains of another the product is called block or graft copolymer

A—B—A—A—B—B—B

Random copolymer



bl e ll d l p s o f the p lymer ı wat u ll s e ll d p lyme l te p lyme em l

P lym r l t ed d tly f w t b ed p nt f dhe e nd f t t g t tiles. Wh p l r l e t ject lyt dd d to the ll d l p th p lym g l t a d t an b p t d nd dried In d t p d pol m m l ı n wh ch h the d d mech al and th m l t bil ty t freq e tly necessary t m d t ly h gh t at ons f l l g t d p tect e ll d Th f emul p lym r g ner lly l p e th n b lk polyme

Th ed x in t t y t m w d l p d fo pol me l q m l In th p ence f te l bl ed g g t h a d m b lfit f ulf t th per d d composes m p dly at t mp t d conseq tly p lyme t t ef l r t tak p at l t mpe tu e By the f the red y t m th t mp r t f th mm l ma l ion pol m t f ty e a d b tad e lo ed f m 50 C t 5 C t f rm ld bb which h gh r in m l l we ght tha the 50 or hot y th tic ubbe

The sp on polyme t on sy tem e eral dv t g By the u of a ery m ll mo nt f u fa t mat ı l and me h l agg g t th m m r c be di p r ed s d pl t in the w te Th m m r ı not c ll id lly disp r ed b t t mp rily b ken up ı t d opl t which w g l te f th t ng we e d c nt nu d In th p e nc f pe de wh h ol bl th m me b lk p lym ı t on t k pla in the d plet Wh n the p lym ız t n e h s me 15–40% th dr pl t t g th d s l ed p ly m b ome st ky d m y o l ce V us ag ts ch s t lc d m t ll o des h e b e mm d d f n e y m ll m t t p e t g l t o the t ky t g At h ghe de g f n th d opl t will b t f med ı h rd b ll of p lymer t g d l d m mer At th mplet n f the polym t th b ll b d ttle t The b d may b d d e ly and r e dy f e I th us- p n y t m th bil ty f p du g

is a meaningless term since its value would depend upon the amount of material present

The end groups of the polymer molecules are the functional groups that have not reacted at any stage It is apparent that at exactly 100% conversion in a difunctional condensation the reaction system would consist of only one molecule The fact that the end groups of a condensation polymer can always undergo further reaction creates a difficulty in the high temperature melt spinning of polyamides and polyesters To prevent subsequent changes in molecular weight such as might occur in the melt during spinning at elevated temperatures a monoacid or monoalcohol (molecular weight modifier) is added to the original polymerization mixture The excess of hydroxyl groups for example places a limit on the chain growth That limit is reached when all the acid groups have reacted and all the end groups are hydroxyl *See* CONDENSATION REACTION

ADDITION POLYMERIZATION

Unsaturated compounds such as olefins and dienes polymerize without the elimination of other products The molecular weight and structure of the polymer are determined by the reaction conditions that is the nature of the catalyst or initiator the temperature and the concentration of reactants monomer initiator and modifying agents The unique feature of addition polymerization is the fact that the average chain length of the polymer formed initially is high and may increase further through secondary branching reactions as the polymerization approaches completion

*The molecular weight range for many useful ad*dition polymers is relatively high typically from 20 000 to several million as compared with the mo*lecular weight range of 5 000–30 000 for typical* condensation polymers

The types of catalysis or initiation which are effective for addition polymerization may be identified in four groups (1) free radical catalysis by peroxides persulfate azo compounds oxygen and *ultraviolet and other radiation (2) acid catalysis* by the Lewis acids such as boron trifluoride sulfuric acid aluminum chloride and other Friedel Crafts agents (3) basic catalysis by alkali metals and metallic alkyls and (4) heterogeneous catalysis by chromic oxide on silica alumina nickel or cobalt on carbon black molybdenum on alumina and complexes of aluminum alkyls with titanium chloride The fourth group may be indeed a sepa*rate group however further information may show* that it is simply a new example of one of the other groups or of some combination of them It is convenient to discuss the mechanism and experimental methods of free radical initiation as one subject and to treat the remaining three types under the heading complex or ionic catalysts

Free radical catalysis Among the several kinds of polymerization catalysis free radical initiation has *been most thoroughly* studied and is most widely employed Atactic polymers are readily formed by free radical polymerization of vinyl and diene monomers and some of their derivatives

At an appropriate temperature a peroxide decomposes to yield free radicals In the presence of a monomer the greater proportion of the radicals adds to the monomer and thereby initiate chain growth The growing chains may terminate by coupling by disproportionation or by transfer with monomer polymer or added material (transfer agents retarders and inhibitors) The series of equations on the facing page illustrates the reactions of initiation propagation and termination by coupling in vinyl acetate

If transfer occurs with the unreacted monomer or polymer already formed higher molecular weight branched structures will be produced and if branching is excessive insoluble products may be formed If the radical produced in the transfer process is not sufficiently active to initiate a new chain the transfer agent is called an inhibitor or a retarder Mercaptans (RSH) carbon tetrachloride and various organic solvents are examples of transfer agents whereas amines and phenols are frequently used as inhibitors or retarders

The rate of free radical polymerization is increased by raising the temperature or increasing the concentration of monomer and initiator whereas the molecular weight of the polymer is increased by increasing the monomer concentration by lowering the temperature and by lowering the concentration of initiator and transfer agents

Polymerization processes The bulk process consists of polymerization of the pure monomer in liquid form On initiation by heat or light or very *small amounts of azobis isobutyronitrile* a very pure polymer can be formed The monomer and polymer are poor heat conductors therefore the tempera*ture of bulk polymerization is* difficult to control A further disadvantage is that small quantities of unreacted monomer are difficult to remove from the polymer Polymerization in solution offers a means of carrying out the polymerization at lower monomer concentrations Because solvents frequently *act as transfer agents polymerization* in solution generally leads to the formation of lower molecular weight products

Polymerization in aqueous emulsion has the advantages of giving a high rate of polymerization a high molecular weight and ease of temperature control A liquid monomer is emulsified in water by use of a surface active agent such as soap The soap micelles provide the polymerization centers *The free radicals (from a* water soluble initiator or growing chains of low molecular weight) diffuse into the soap micelle in which they react to form relatively linear polymer of high molecular weight The polymer particles of small diameter 500 1500 A are in stable suspension because the soap of the original micelle remains adsorbed in the outer layer of the polymer particle The rate of emulsion polymerization and the molecular weight of the polymer increase with increasing number of micelle particles per unit volume The product *as*

¢ Acid and ba e Addition reaction Cataly si Chain reaction chemical Fiber man m de Free radic l Inhibitor (chemical) Ki etics (che iical) Organic reaction mecha m Oxidation reduction Plastics fabrica tio Polymer Polymer properties

[J A M L M H]

Biblio aph E C. B nha dt (ed) *P oces g l Th pl t c M t als* 1959 II Gold ng *P lym a d Re n* 1959 II Mark et l (eds) *R sh P l m s* 1? ls 1940–1958 *Moder Plas n E cyclop d a* vol 37 1960 W J Roff *F bers Plasti nd R bb s* 1956 C E Schildk echt *I l d R l ted P lymers* 1952 A X Schmidt a d C A Marl es *P inc pl of High P lyme Th ory d P acti e* 1948

Polymorphism (crystallography)

Th p p rty f ryst ll ng in two mo e f rm Th term i ppl d t cry t ls f the ame sub- st ha a d ff e t tru tu S bst ce ch as CaCO h h t n tw crystal f rm e a d to be dim rph h le b t ce u h as T O h h pp in th e f rms re te med t im phou The p lym ph m d fi at s of C CO e a g te wh h rth h mb d lcit h h trig al The m d fi ti f TiO a e ru le (tet g n l) at e (tet o l) a d b ok te (orth h mb) Th m difi at a st ble t n rm l t mp tu e d i c mpa ble tempe t e r Othe p lym rph f m h as those f S O (q tz, c t ball t trid m te) ha p fic rlappi g t b l ty ra ge P W Bridgm d er d m ny p lymorph od fi t n h h o ly stable de high pres Th p lymo phic form f th el ment are call d all t pi mod fi t n S Crystal structure

F m a t tu al t dp t m le ul p l nt d t h g w th t mp t e m port t fact bt g ng b t ch ge f m rr t t th r F r b t e h g p ly m rph f rm t bl t th s me t mp tu the at m c t e h th t th y e t th l m t of the t b l ty f a t u t Th fo d t h t mp t t e t rnal c d ry co ar l rm d p e r d mp t s

P l t p m i p lym phi m rr w a d prefi e Th t rm i ppl d t b t h g t u t l k th t f z bl d Th bl d tru t r n be des b d a l p ck ng f ulf l er l m l ng m t h g d b d bet n Call g A B C th th p ll po t f lf lay d A B C th l the t t e f n bl d h tt ymb l lly AA BBCCAABBCC A polytyp t t h ABC p d k pe ted M p l typ f b ru d m a l n Th oc l h p lytyp h fully pl t ed by th p l g wh f y t l F d c

cry t l tructu e of p lymorphous mineral *Se* Mineralogy [W D]

Bibliog phy H Ba mhauer *Z Krist* 55 49 1915 H C E ans *Int o luct o to C ystal Chem ist y* 1939 F C F ank Gr wth f carborund m di l c tio and p lytypism *Ph l Mag* 4?(33?) 1014–1021 1951

Polymyxin

The b polypept de ant biot produ ed as e of the f rment ti n p d ts wl en ce tai tra n of the ba te ium *Bacillus p lymyxa* re gr n in uit ble n trient P lymyxi antiba te ial acti n uniq ely d ected nly toward certai gram eg t bacte ia F examples of lypeptides acti e agai t gram p iti ba teri *see* Bacitracin Subtilin

Prior t p bl c d el re in 194 d elopme t l work n p lymyxin h d take pla ind pe de tly in laborator e t the Unit d St te nd Great Br t ain The Br t l n e t gat rs fi t publ hed o p lymyxin unde the am a o p ri dopted f m *Ba llus e po s s* nym f *B poly myxa* Det led h m al t d e on the p r fied nt b oti formed by ch f umber f *B p ly myxa* t a s re aled a fam ly f l ely r lated lymyx F rth m st gle t a n pr d ced nly e member f th fam l

Only th i e d α y d am o buty ic a id re mm t ll of the member of th f m ly The m Ca pt ally a t e f tty d pr e t n ll member h s b e ide tified D-6-m thyl ta l id

Purification and chemical properties At the c mpleti f 48– 2 h u s f f rment t n t me at 26–28 C th t bi t m y be r m d f m the ult e b oth bv d pt n n a t v ted arb n d then w h d ff the b by a d m tha ol P p t t n et f ll w d by e t t n nt b tyl l hol nd fi ally c n er t p l ym n hyd ochl ide Th l tte p odu t i ea ly l l wh te p wd ry ol ble w t and m th l lt l ble ethe este s k t s hyd b d hl r n t d s l e ts Th mol ul we ght r ge f m 900–1150 Th ly p lymyx n typ f whi h a stru tu l f rm la h s bee p tul ted p lymyx D in 1949 The i hes t t n t fy ny a r g me t f the g up the g t t e b 5000 p b l t uld e t

Ami d mpon f th polymyx

P ly myx type	Le	Ph yl l	Th eo-	Seri	α γ-d m b tyri cid
A	+		+	−	+
B	+	+	+	−	+
C	−	+	+	−	+
D	+	−	+	+	+
E1	+	−	+	−	+

Prese (+) bse (−) f d m l l

pure polymer in bulk polymerization is combined with the ease of temperature control in the aqueous emulsion polymerization There is the additional advantage that the product of suspension polymerization can be easily isolated for use

Complex or ionic catalysis Some polymerizations can be initiated by material often called ionic catalysts that contain highly polar reactive sites or complexes The term heterogeneous catalyst is also applied to these materials because nearly all the catalyst systems are insoluble in monomers and other solvents These polymerizations are usually carried out in solution from which the polymer can be obtained by evaporation of the solvent or by precipitation on the addition of a nonsolvent

A general mechanism is shown in the following equations in which the growing chain is represented as an activated complex with the complex catalyst without attempting to specify whether separate ions or free radicals are involved

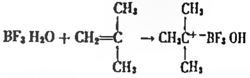
Complex catalyst + M → CM*	Initiative complex
CM* + M → M*CM	Initiation
M *CM → M + CM	Termination by decomposition of complex
M *CM + M → M + M*CM	Termination by transfer to monomer

The distinguishing feature of complex catalysts is the ability of a few representatives of each type to initiate stereoregular polymerization or to cause the formation of polymers which can be crystallized The polymerization process is visualized as the formation of an activated complex of the monomer with the complex catalyst For stereoregular growth to take place the entering monomer must collide with the complex and be adsorbed in an oriented fashion As reaction takes place the new monomer assumes an activated condition within the complex catalyst and at the same time pushes the old monomer unit out Chain growth is therefore similar to the growth of a hair from the skin

The effect of conditions on rates of polymerization and on molecular size and structure is not yet fully understood In general the rate of polymerization is proportional to the concentrations of complex catalyst and monomer The effect of temperature on the rate depends upon the stability and activity of the complex catalyst at the temperature under consideration If the complex catalyst decomposes on increasing the temperature then the rate of polymerization will be reduced The effect of temperature upon molecular weight also depends upon the stability of the complex catalyst and upon the relative rates of propagation and termination In some cases at an optimum temperature of polymerization the molecular weight depends upon the product of the ratio of the rate of propagation to termination and the monomer concentration and in other cases only upon that ratio of rate

Examples of polymerization with the different types of complex catalysts are briefly described in the following paragraphs

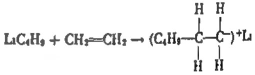
Lewis acids Carbonium ion catalysts such as BF_3 $AlCl_3$ or H_2SO_4 usually require the presence of a promoter such as H_2O or HCl



Complex catalyst Isobutylene Initiating complex

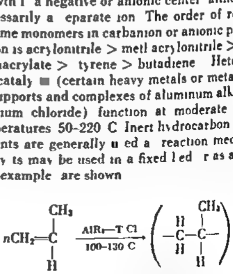
It has been suggested that the point of chain growth is a carbonium (positive) ion although it is not contended that the ion necessarily has more than a transitory existence Polymerization in the presence of Lewis acids takes place very rapidly at low temperatures −100 to −0 C The order of reactivity of some olefins in Lewis acid catalysis is vinyl ethers > isobutylene > α methyl styrene > isoprene > styrene > butadiene

Alkali metals and metallic alkyls Carbanion catalysts such as sodium lithium and lithium butyl function at moderate temperatures 25–150 C In ert hydrocarbon or ether solvents are generally used as reaction media

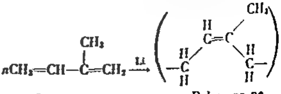


Lithium butyl Ethylene Initiating complex

It has been suggested that the point of chain growth is a negative or anionic center although not necessarily a separate ion The order of reactivity of some monomers in carbanion or anionic polymerization is acrylonitrile > methacrylonitrile > methyl methacrylate > styrene > butadiene Heterogeneous catalysts (certain heavy metals or metal oxide on supports and complexes of aluminum alkyl with titanium chloride) function at moderate to high temperatures 50–220 C Inert hydrocarbon or ether solvents are generally used as reaction media The catalysts may be used in a fixed bed or as a slurry Two examples are shown



Propylene Isotactic polypropylene



Isoprene *cis* Polyisoprene

$R(f,g) = a$ b $(_1 - s)(r_1 - _2)$ ... $(_1 - s_m)$
$(_2 - s)(_2 - _2)$ ... $(- s_m)$

$(- s_1)(- _2)$ ... $(- s_m)$
$= g(_1)g( )$ ... $g( )$
$= (-1)$ $b_m f(s)f(_2)$ ... $f(s_m)$

i f rm f th es lt t i ften ful if ll f t fo f the p ly om l a kn wn
The meth d f sol ing ystems con t ng f eth t o q at n w ll be ll t ated by c n r ga yst m

$$f(y) = 0$$
$$g(x y) = 0 \qquad (4)$$
$$h(x y) = 0$$

b f f g d h re co d ed t be polynomials in x th coeffic ent wh h a e poly m al r and z If th sy t m h s a sol t o $x = a$ $y = b$ c then fo $y = b$ $z =$ ea h p r of equat s a comm n root $x = a$ H c $R(f,g) = 0$ $(g,h) = 0$ a d $R(f,h) = 0$ The e l tte eq a te p lyn mi ls in y nd z d f z = y h e ommo root $y = b$ He $R[R(f,g)$ $(g,h)] = 0$ $R[R(g,h)$ $R(f,h)] = 0$ d $R(f,g)$ $R(f,h)] = 0$ Th e thr e eq t p l n mi l n nd g e e y d t the sy t m (4) t h a l t on H w e condit e t ge eral s ffici t That t i p ibl f r alu of z t s t sfy all three t th ut y t m (4) ha a lut erthel n ma y a e th eq at s m k o ble t t ll wh the ystem (4) h s lut to fi d th m Th f ll w g mpl will l t th m thod

$$f(y) = \quad - y + \quad = 0$$
$$g(y) = x + \quad - y = 0 \qquad (5)$$
$$h(y) = x + \quad + 1 = 0$$

$R(f,g) = y - 2z\,y - y + z + z$ (g,h) $y -$ $+$ $+ 1$ nd $R(f,h) = -y +$ $3 + 1$ Th ary o d t o ar

$$R[R(f,g)\ R(g,h)] = 2(2z + 1) = 0$$
$$R[R(g,h)\ R(f,h)] = 2(2 + 1) = 0$$

$$R[R(f,g)\ R(f,h)] = 4(2 + 1) = 0$$

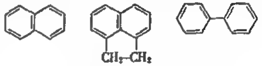
$z = -\frac{1}{2}$ the nly alue f t sfy ng the ry d t ons In y tem (5) $= -\frac{1}{2}$ g $-\frac{1}{2}$ nd $y = -\frac{1}{2}$ S c th l s t fy ll e equ t th th un q e s l t f ys (5)

th m thod f l m t ppl bl n th quat o s f y tem (1) h p l If f th q t s l e a y t m u h n q t c b l ed f of th les a d th bl n be l m ted Sy h h l ne (LINEAR SYSTEMS OF EQ) i p w f th bl m y b ed by th m thod ppl bl t l y t m F CATI S THEORY F [R A B]

Bl g ph B L de W de M d ba 1 1 19 3

Polynuclear hydrocarbon

On f a class f hyd ocarb ns p e i g m e tha ne ri g The ar mati poly clear hydro c bo may be d ided nto two g ups In the fir t the ing e f ed wh ch m an that at lea t tw carb n at ms a e sha ed betw en adjace t ring E amples are phth le (I) whi h h tw 6 memb ed ng and ac phthen (II) wh h tw 6 m mb ed ri gs and o e 5 mem be d ri g



(I) (II) (III)

$C_6H_5CH_2CH_2C_6H_5$
(IV)

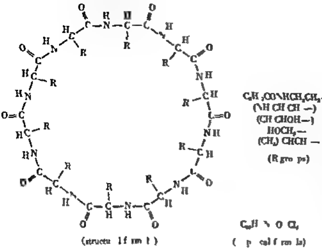
I the seco d g oup f p ly cl r hyd oc bo th r mat ri gs j i ed th r d rectly a n the e f b ph yl (III) th gh char f e m e c rbon tom in 1 2 d phenyl eth ne (IV)

P ly uclea hyd o b n r f u d n the h ghe b li g c l tar f a t o s but m esp ci lly th w tho t c d ed r g f ex mple (III) a d (IV) are m st ead ly bt n d fr m be en de ati e by ynthe S ANTHRACENE AROMATIC HYDROCARBON BIPHENYL DIPHENYLMETHANE HEXAPHENYLETHANE INDENE NAPHTHALENE PHENANTHRENE STEROID TRIPHENYLMETHANE [C K B]

Polyolefin resins

P lyme d d f om u t r t d hydr ca b n c tai g th ethyl r d ne g up Br adly p lyolefi s may i l d i tu lly ll dd ti n p lymer h we e the term poly l fi s pe fi lly u d f polyme f ethyl n th alkyl d i t f ethyl e (α ol fi s) nd the d e e Th p lyv yl e n the fi r bo p lymer a d oth dd ti polym a e e ed the art l Thi t l n l des d e of th pol ym f th l n p opyl a d b tyl e a d b ef me t m de f p lymer f the α l fi d f b tad e n d 2 hl ob t d e S POLYFLUOROOLEFIN RESINS POLYVINYL RESINS

Polyethylene P lyethylen is wh t h t n l t p lyme of m d r t t th nd h gh t gh Th labl f rms e p t lly c y t ll e Th phys l p p rt y m k dly w th th deg f y t ll ty The d n d f th p d t n e w th r g d g f y tall ty d t s mm t l fy th c mm c l g ad sl w d ty ($d < 0.925$) m d um d ty (d 0.925–0.94) h gh de ty ($d > 0.94$) W th g y t ll ty d ty th p d t b me t ff d t e a d ha h gh oft g t mpe t s d h gh es t e t t t by l q d d g e t th m t m they l m f th



P lymyxin D hydrochl d

Toxicity The least toxic member of the family is polymyxin B However administration of type II to humans via the parenteral route is not advisable unles a erious infection by a polymyxin su cepti ble bacterium has not responded to previous treat ment by other chemotherapeutic drugs The patient must be hospitalized so that possible toxic effects of polymyxin therapy such as proteinuria or nitro gen retention may be quickly ascertained The drug has been formulated into ointments and tro ches alone and in combination with other antibi otics and in this manner has been successfully u ed for topical treatment of arious infections

[R C BE]

Bibliography E Jawetz *Polymyxin Neomycin Bacitracin* Antibiotics Monograph 5 19 6 P H Long et al Antibiotics derived from *Bacillus polymyxa* *Ann N Y Acad Sci* 51(5) 853–1000 1949

Polynomial systems of equations

Systems of mathematical equations of the form

$$\begin{aligned} f_1(x_1\ x_2 \qquad x\ ) &= 0 \\ f_2(x_1\ x_2 \qquad x\ ) &= 0 \\ \\ f_m(x_1\ x_2 \qquad ,x\ ) &= 0 \end{aligned} \tag{1}$$

Each $f\ (x\ \ x_2 \qquad x\ )\quad i = 1\ \ 2 \qquad m$ is a sum of terms of the form

$$a \qquad x_1\ x_2 \qquad x$$

where the coefficient

$$a$$

i a constant or fixed number and the exponent i_j of the variable x_j is a nonnegative whol number An example of such a sy tem in two variables is

$$\begin{aligned} x^2 - xy + y^2 - 1 &= 0 \\ x^2 + xy - 3y^2 - 2x + 2y + 1 &= 0 \end{aligned} \tag{2}$$

The expre ions $f\ (x_1,x \qquad ,x\ )$ are called poly nomials in everal variables The problem po ed by y tem (1) is to find nece ary and sufficient conditions that there exi t values of the variables $x\ = a\quad x\ = a \qquad x\ = a$ which simultaneou ly ati fy each equation of the sy tem and to find all such sets of values which are called olu tions of the system In example (2) a complete et of solutions is given by $x = 1\ \ y = 0\quad x = 0\ \ y = 1\quad x = 1\ \ y = 1$ and $x = -1\ \ y = -1$

The equations of system (1) can be written as polynomials in one of the variables for example x_1 with coefficients which are polynomials in the remaining variables $x\ \ x_3 \qquad x$ If sy tem (1) has a olution then for certain values of th vari ables $x\ = a\quad x_3 = a_3 \qquad x\ = a$ the equa tions of the system as polynomials in x_1 have a common root $x_1 = a_1$ The proce s of finding a condition involving the variable $x\ \ x_3 \qquad x$ which is both necessary and ufficient for the equa tion to have a common root $x_1 = a_1$ is called eliminating x_1 from the equations In the example (2) it can be shown that if x i eliminated from the equations the condition $12y(y-1)\ (y+1) = 0$ is obtained Corresponding to the values $y = 0\ \ 1\ \ -1$ which atisfy this condition the four solutions of the sy tem given earlier are obtained

Example (2) illustrates a system of t o polyno mial equation which can be written in the form

$$\begin{aligned} f(x) &= a\ x\ + a\ _{-1}x\ ^{-1} + \qquad + a_1x + a_0 = 0 \\ g(x) &= b_mx^m + b_{m-1}x^{m-1} + \qquad + b_1x + b_0 = 0 \end{aligned} \tag{3}$$

where the coefficients are either constants or poly nomials in the variables $y\ \ z$

The resultant of the polynomial $f(x)$ and $g(x)$ of (3) is the following determinant (*see* DETERMINANT) with elements which are the coeffi ients of the given polynomials

$$R\ (f\,g) = \left|\begin{matrix} a & a\ _{-1} & & a_1 & a_0 & & \\ & a & a\ _{-1} & & a_1 & a_0 & \\ & & & a & a\ _{-1} & & a_1\ \ a_0 \\ b_m & b_{m-1} & & b_1 & b_0 & & \\ & b_m & b_{m-1} & & b_1 & b_0 & \\ & & & b_m & b_{m-1} & & b_1\ \ b_0 \end{matrix}\right| \begin{matrix} \left.\vphantom{\begin{matrix}a\\a\\a\end{matrix}}\right\} m \text{ ro } \\ \left.\vphantom{\begin{matrix}a\\a\\a\end{matrix}}\right\} n \text{ ro } \end{matrix}$$

where it is understood that the blank spaces hould be filled with zeros The re ultant in this form is called Sylvester s determinant It can be proved that the condition $R\ (f,g) = 0$ is both nece ary and sufficient for $f(x) = 0$ and $g(x) = 0$ to have a common root $x = \alpha$ provided not both $a\ = 0$ and $b_m = 0$ In the example (2)

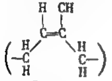
$$\begin{aligned} R\ (f\,g) &= \begin{vmatrix} 1 & -y & y^2-1 & 0 \\ 0 & 1 & -y & y^2-1 \\ 1 & y-2 & -3y^2+2y+1 & 0 \\ 0 & 1 & y-2 & -3y^2+2y+1 \end{vmatrix} \\ &= 12y(y-1)^2(y+1) \end{aligned}$$

It does not matter in which order the polyno mials $f(x)$ and $g(x)$ are taken a it can be ho n that $R\ (g\,f) = (-1)^m\ R\ (f\,g)$ Let $r_1\ \ r \qquad r$ be the roots of $f(x) = 0$ and $s_1\ \ s \qquad s_m$ be the roots of $g(x) = 0$ The re ultant can be written in the following factored f rm

The h gh melti p lym s a the subject of co d ble inter t becau e relati ly few the pla.tic polym are a ailabl which hav high ftening temperat and t th ame t me c be e l f b cated

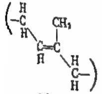
Polydienes t diene isopr ne nd 2 chlo o-b t d ne ha e g ned the w de t use f die es em pl ed i th polymer field Butad ene d 2 chlo-r but dien have long bee used i the produ tio f synthet rubbers by free-rad cal taly is The sopr e tructur ha long been rec g i ed to c respo d to the repe ti g u t n natur l rubber S RUBBER.

Spe l st pe ifi cat lysts are u eful in the polym rizat n f but d e nd i op en N tural rubbe n ts la g ly f c s polyisopre

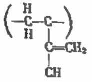


cis P lyi op en

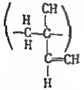
d cha teriz d by h h el t city a d l w i l m l f t n (o fle g) The polyme f b ta d ne a d sop e f rmed by fr r di l taly s cont m t f the ci and tr ns form to geth th som 1 2 3 4 tr ct r m tur f ll f r f rm



trans P ly p



1 Poly s pr ne



3 4-P ly s p ene

Th p se of t an a d 1 2 d 3 4 tr ct e a se the rubbe t h l we l st city nd h gh r i t rmal f ti n on fi x g

Th appl at f th t pe fi at ly t t th p lym at n of p ne d b t d e ha led to th d l pme t f ynth t c bb s wh ch cont n h gh prop rt f the c s t tu nd h h e nt lly q lent in p pert e t n l ubbe S A DITION RE CTION ALKE E 1,3-BUTADIENE DIE E I OPRENE PLASTICS FABRI ATIO POLY IERIZATI [J A M L M H]

Polyoxyethylation of alcohol

Th p oces of ff ct g t f al h l with h len d t p od c p ly the The p ly h so p od ed h te d by r n l have th fo mul R—O—[CH₂—CH₂—O—]ₙH n wh ch *n* repre nts an integer fr m 1 to 20 and R repr nts the alkyl re idue f the l h l ROH

Although p lyo yethylation f alcoh ls is for mally a p lyme ati re tion the p d ts are ot f th e tremely high molec lar weight that characte zes the h gh p lym rs obt in d for e am ple by the p lyme zati n of rga inyl m o-mers In f ct a p al d usef l class f c m p und in which *n* = 1 in th ab ve f rmulat n can be bta ed by varying ea t on nd tion this p o i known as hyd oxy thylatio of al cohols As ul howe er th product are low mole ula we ht polyethers i th mole ular weight ange of 200–1000 S e POLY IERIZATION

P lyo yethylat n f alc hol i ac mpli hed by he ti the lcoh l a d thyl e ide i the pr enc of c t ly t c mp nd b th dic nd ba ic are effecti lyst The m lec ular we ght and atu e f th pr duct are deter m ned by th am nt a d kind of cat ly t t me nd temperatur f eact n and m lar ratio of thyle e o de t al oh l The la ge r t o f eth ylene o de t al hol gener lly gi e the higher m l ul w ght p l ther The r ct o is l m t d t pr mary a d nd ry al hols

Th p ly th p d t ithe i u liquids l w melti g w xy l d which are l ble in water d mo t p lar rgani l ent They re ef l a water l ble lub i nt mul fy ng ge t d f rmul nts fo m tic and i t me ts adhe e d p p at g P ly y th ylat n f methanol l d to mm c l products m k t d a Meth xy Polyethylen Gly ol wh ch a e im l r t th e mmer al P lyethylen Gly l (C bow)

Th y a e l m la n tr t to p l (thyl e xid) lth ugh the latt p lym s re f mu h h he m le la w ght a d r p par d by d ff e t p e s Se POLYETHYLENE GLYCOL [D L H]

Polyplacophora

An d al kn wn s the Lor ta of the l s Amph The m ll ks mm ly ll d hit s Th b d ll pt al a d th d l h ll mpr e ght l n pl te wh h e l p p st ri ly A mu ul r gi dle r d the plate Th pl te n mp d f tw l yer the ner a ti lam t m a d te t gm nt m Th latte nt n t de m l t e l c ted n l wh h t m nat phot tr ph t u t r th a thete G ll wh h mble t n d y numbe from 6 to 80 p Ch t o r hall w t l wat r a d f m the O d i to th t Comm mple *Ch t n T ll Ch topl C ped h l* a d *Crypto h t* S AMPHINEURA [C B C]

Polyploidy

The c e f l ted fo m p s i g ch o-m m umb r h h

and stress cracking and higher temperatures and pressures are needed for molding

Polyethylene is produced in very large volume The major uses are as packaging films container molded articles electrical insulation wire coating and pipe

Ethylene is produced on a large scale by the cracking of aliphatic hydrocarbons found in petroleum The monomer can be conveniently produced in smaller volumes by the catalytic dehydration of ethanol

The low and medium density polymers are formed by the polymerization of highly purified ethylene at about 150–250 C and 20 000–35 000 psi in the presence of a very small amount of oxygen or organic peroxide At the higher temperatures *the low density polymer is formed and at the* lower reaction temperatures the medium density product is produced

$$n\mathrm{CH_2{=}CH_2} \xrightarrow[\text{Oxyg}]{\substack{200\ \mathrm{C} \\ 25\,000\ \mathrm{p}}} (\mathrm{-CH_2-CH_2-})$$

Polyethylene

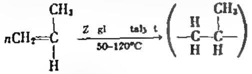
The high density polymers are formed at relatively low temperatures and pressures (for example *50–150 C and 100–2000 psi) in the presence of* special catalysts often referred to as stereospecific catalysts These include oxidized forms of certain heavy metals such as chromium reduced forms of heavy metals such as cobalt and nickel and the Ziegler catalyst a complex of an aluminum alkyl and a titanium chloride

For the low density material the softening temperature and the maximum temperature for continuous use are about 105–115 C and 75 C respectively the corresponding temperatures for the high density product are some 25–40 C higher

Structural studies have shown that the higher density polymers have highly linear structures and are approximately 85–95% crystalline The lower density materials are branched and are 50–85% crystalline *See* ETHYLENE

Polypropylene High molecular weight isotactic highly crystalline polypropylene is generally similar in properties to high density polyethylene In comparison with the latter isotactic polypropylene is harder and stronger and softens at about 160 C

Propylene is available in large quantities from the cracking of petroleum hydrocarbons and the high molecular weight isotactic polymers are formed in the presence of the stereospecific catalyst used in the ethylene polymerization



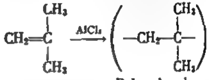
Polypropylene

The crystalline product has been recently introduced and should have many uses for molded objects film and fibers

The low molecular weight polypropylene oils formed in the presence of acid catalyst such as boron trifluoride or phosphoric acid are useful in the manufacture of gasoline and synthetic detergents but are not employed in plastics technology *See* PROPYLENE

Polyisobutylene The polyisobutylene polymer vary in properties from low molecular weight oils to high molecular weight rubbery solids

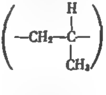
The monomer obtained by cracking petroleum hydrocarbons readily polymerizes in the presence of acid catalysts such as boron trifluoride, aluminum chloride or tin (IV) tetrachloride



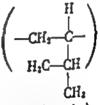
Polyisobutylene

Polymerization conducted at 0–25 C yields oils which are useful in calking and sealing compositions At low temperatures such as −100 to −80 C rubbery solids are formed The solid are also useful in calking compositions and adhesive formulations however the main use of polyisobutylene is in the form of the copolymer with 2–4% isoprene The copolymer known as *butyl rubber* can be prepared at −90 C in the presence of methyl chloride as a diluent and aluminum chloride as the catalyst The product distinguished by its impermeability to gases and its resistance to aging is used in automobile tires and tubes

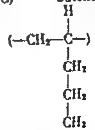
Polymers of other 1 olefins The discovery of the stereospecific catalysts listed for ethylene polymerization has made possible the formation of high molecular weight isotactic crystalline polymers of other 1 olefins such as 1 butene 1 octene and 1 dodecene The softening temperature (sp) of the crystalline isotactic polymers of some of the 1 olefins are relatively high



Polypropylene
(sp 176 C)



Poly 3 methyl
butene 1 (sp 300 C)



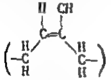
Polypentene 1
(sp 75 C)

The high melting points of certain of the isotactic crystalline polymers may result from special spatial arrangements necessary to accommodate the presence of bulky branched group near the polymeric chain

ı h gh-m ltın pol mers are the bject of ıd r ble ınt rest bec u e relatı ely few ther laıı pı l m rs a e ılable which ha e higl ning tempe ıı res and at the ame time a be ı f bri ated.

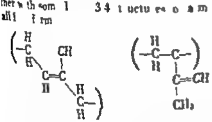
olydienes Butad ene ı pre e a d -chl r ı-ıd ene h e gaı ed the widest u e f dienes m ed ın the polym r field Butad en and -chlo-ıtad e e h ı l ng been used ı the pr du tı n ynthet c rubbers by free-rad c l cat ly The ı en stru t re ha l ng been rec gn zed ı e r ıo d ı th r peating u ıt ın n tural r bber Rcв ER.

ipe l t en pecific c tal t a m ful ın the ymerızatı f b tad an l ı pte e N t ral ıb ı ı larg ly f cıs p lyı op ene

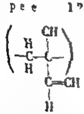


cıs-Pol pren

d ch act rızed by hıgh l t cıty a d l w ın nal f tı a (fte g) Th p lyme f b t e nd ıop e e f m d by free-rad c l ı ly ı mı tures f th ı and tr s f m to-ther w th som l 3 4 t uctu es o a m ture all f rm



tran Poly p e e 1 2 P ly sop ı



3 4-Pol p n

h p ese e l tr s nd 1 2 d 3 4 tru tu s a es th rubb r to h e l w r ela tıc ty d ı h ınt rnal frı t n n fl xıng

Th ppl t n f th te pe fi cat l t t h p lym ızat f ıop e a d b t d ha led t the d l pm nt of y thet ubbe wh ch ıo la h b ı p rt of th tr ture nd whı h ı lly q le t p p t es t nat ral rubbe S ADD TION REACTIO ALKE E 1 3-BUT DIE E DIENE I OPRE E PL STICS FABRI C TION POLYMERIZ TIO [J A M L M H]

Polyoxyethylation of alcohol

Th p oces f effect ng r t n f al h l w th hyl n o de to p od ce poly th The p ly eth ı so p od ced a ... ha e the f rmula R—O—[CH₂—CH₂—O—]ₙ H ın wl ıch n represent an integer f m 1 to 0 and R rep es nt th alk l resıdu f th al l l ROH

Alth ugh pol xyeth lati of al l l ı f r mally a pol me t tı n r a tı n tl ı odı t are n t of the e t mely hıgh m l cular w ıgl t that ll ra t r ze the hıgl pı l mer bta d f r e am pl by the polym rızat f rga ıc ı yl m no-me In fact a pecı l nd ı f ıl el of c m pı ı l ı wl h n = 1 ın th abo e f rmulatı n e n l e oltaıned l y varyıng r a tı n c d tı n ll proces ı k wn a h dr xyeth lat n f al col l A a r ıl l ever the pr d ı t ar l w m lecular weıgl t polyether ın th m lecular w ght range f 200–1000 S POLYMERIZATION

I ly xy th latı n f alc h l ı a mpl hed b ll atı g th l h l n l thyl e o d ın the pres c f atalyt ı taın ı mpo ınd both a dı a d l a are ffect ı ataly t Th m lec lar weight and nature of the prod ct ar d ter m ed l th am t nd kınd f ataly t t me and tempe at re f e a t nd m l r rat of thylen d t al h l Tl l rg r at f eth lene o d t lc l l g nerall gı the hıgh r m lecul r w ıgl t pı l th r Tl t ı l m ted t pr m ry and dary l l l

Tl p l ethl pr du t ar tl l ıı d o l w meltı g w xy l d wl ı h ar l l l ın w te and t p lar ga c l nt Th y are f l a wate sol l l l l ı t mıl f ı g ag t d f rmul nt f r cosm tı and t m t adhe es and p pe c atıng P ly xyeth yl t n of methan l l ad t mm rcıal p od ct ma k ted a M th y P ly thyle e Gl col wh h a ım l r t the omm cı l P l th l e Gly l (Ca bow)

Th also ım l t t t t pol (th l e x de) lth ugh the latt pol m are f mu h h gh r m lecul r w ght nd are p epa ed b a d ff r t p S POLYETHYLE E GLYCOL [D L.H]

Polyplacophora

A rd al k w the Lo ıcat f the) Amph eu a The m ll k a mm nly alled hıt n The body ll pt l a d th d al hell mpr e ght l a eo pl t which o lap po t r l A mu ul g dl s u d th pl tes The plates e mp d f tw la r the ınner rtı ulam nt m a d o t tegme t m The latt r t ı tod m l tı u l at dı l wh h t rm n te ph t t ph c t u tu th esth te G ll wh h mbl t d rv mb f m 6 t 80 p Chit c ı hallow t l w te d r n e f ıı the O d n to the Re nt Comm e ampl a *Ch to To H Ch et pl u C u ped hılu* nd *Crypto h t* S AM HINEURA [C B C]

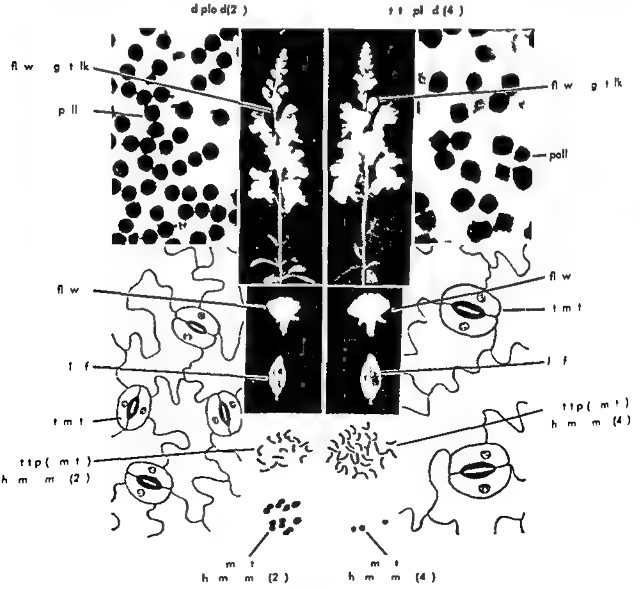
Polyploidy

Th o ur n e f l ted f rm p e g ch o

chromosomes are triploids 4x tetraploids 5x pentaploids and so on Autopolyploids are forms derived by the multiplication of chromosomes from a single diploid organism As a result the homologous chromosomes come from the same source These are distinguished from allopolyploids which are forms derived from a hybrid between two diploid organisms As a result the homologous chromosomes come from different sources About one third of the species of vascular plants have originated at least partly by polyploidy and as many more appear to have ancestries which involve ancient occurrences of polyploidy The condition can be induced artificially with the drug colchicine and the production of polyploid individuals has become a valuable tool for plant breeding

Polyploid series are irregularly distributed through the plant kingdom They are particularly common in some families notably the Gramineae and Rosaceae and are rare in others such as the Fagaceae and Umbelliferae Not infrequently there exist related genera of the same family one with and one without polyploidy such as *Thalictrum* and *Aquilegia* of the family Ranunculaceae or *Salix* and *Populus* of the family Salicaceae Polyploidy has a significantly higher frequency in perennial herbs than in annual herbs and woody plants A polyploid series often cited is that of the wheats in which the basic chromosome number is 7 and somatic chromosome numbers of 14 28 and 42 occur

In animals undoubted examples of polyploidy are confined to groups which are parthenogenetic such as crustaceans of the genus *Artemia* certain earthworms weevils of the family Curculionidae moths of the genus *Solenobia* and sawflies of the genus *Diprion* or which produce asexually by fission as the flatworm *Dendrocoelum infernale* A partial explanation of this situation is that in many animals the sex chromosome mechanism is so upset by polyploidy that sterile intersexes are produced Because hybrid sterility in animals is usually genic rather than chromosomal in nature and is not eliminated by chromosome doubling allopolyploids can occur only rarely Genic hybrid sterility as in the mule is the result of genes contributed by the parents interacting in the hybrid to disturb the course of meiosis and sex cell



F 1 D plo d d tet aplo d s pd og

m t Chr m mal hybr d te il ty a the r
li f the bil ty of hom l g us chrom m
pai t meiosis du t rearra gement of the
es the ch om me by a ch om mal aber
t h as in er i n tran l cat n r def
ency

Hybridizat on P lypl dy nd hyl rid zat re
all a oc ted w th eacl th r i e ol iti
h d t tly related species are r ed the
ril F hybr d ften ha l ttle r n m ti
i ome p g H wev r in m cell the
mmosom mpl ment nd g es d i ll g
di g t the f rmati f a few eed fr m wl ich
e d gen at hybrids re f rmed Th f rtil
ol pl d d ri at e p es es ly b al nt s
m t b eed true f r th termed ate ndit n
h a polypl d i des gnated ll polypl d Well
wn e amples are b d whe t (*Triti um*
m 2n = 4) culti ated t bace (*N t a*
b um, 2 = 48) d *Raph b as c* (n =
6) h h the hybrid betwe radi h (*Raph nus*
n = 18) and cabbage (*B ssi l c a*
18) P lypl d ha al r gi ted l m
ybrid b t ee cl sely rel ted p ies (*I ami la*
us) or b t ee sub pe ies f th same pe
es (*D ctylis gl m t*) These des gn ted
me t l llop lypl d d ut p l plo d f
b d espe t ely Such p lypl d may
m ry g mbe f tr al t and q dr ale t
hrom som *e figu tion* a d so may seg gate
n th d ti of thei p t l typ Aut p ly
pl d derived f m a gl d pl d rac h l e
prod ced m ny t *mes a t ficially* b t re e in
nat e e they are ually w ker and l
f rtil than the d pl d pr g t In many pl t
genera, the m lt eo oc r e f everal
P lypl d f th th e *typ* pl s oth wh h
b h act t c of to- and all p lypl idy
th th d pl d a e t r ha pr d d
th pol pl d mpl x *Th* i ts f a eries of
n ll d t ct d pl d p c e b p e which

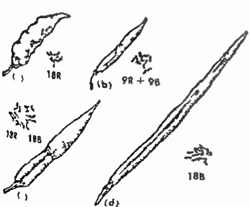


Fig 2. S d p d d m t h m m mple-
ments f d h bb g d hyb d b tw th m
18 dish (R ph) (b) The d pl d hyb d f d h
b ss (d) C bb ge (B ...

repre m t ext m f m rgh l gical and ec l gi al
vari tion pl a m h larger numl r of p lypl id
which f rm a n tw k f c n ecting l nk l tween
the d pl i l Examples ar *B mus l i ium*
C l um a l f te atia

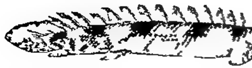
Distribution Th geog ph c d tril uti n f
p lypl id m r l t t th s lypl l an t r
l e n t f ll w a y n i t t et f r iles Certain
n rth rn regi su h a le la l a l Spit berg n
h fl ra w th pa ti l rly high p r entag of
p lypl ids l t d m regi with ltr p al
r e en t pi al climat ch a New Zeala d and
Ce l Lowlan l d dja t high alpin fl t
we t r Fur pe d n t d ff r gnif antly in p r
tage f p l pl i l Dipl id repre tati of
i di idu l p lypl d mpl xes t d t oc upy
geol g ally l le hal tat a l t tr p l l are
m t prevale t i regi n n wl p t e l niza
ti n Co q ently th l rger ld r and more
t ll land m l a e r lat ly l gh p r nt ges
f dipl d while i l nd with fl de i d
thr gh immigr t n a d ar a di turbed l y
gl ciati n l nic acti ity or th r c ha e
high p r ntages f p l pl dy

Plant breeding Artificial polypl i l ha e l ee
prod ed in m t f the maj p cies f r p
plant l y t t g ed e c tt ng with l l in
C lly th y ha l ee les i f l tha thei
dipl d p g t l eca i e f the r lo gr wth
d red iced fertility l t e n mi ally l al le
a t p lypl id ha been prod d in r e ug r
beet peseed l r d l r pdrag m ri
g ld ar ch d and m ther pl t
S e h he n h ed ly when the d l l g
ha been a mp ted by int rvar tal h l r d
t d ele ti n Alth gh r l artif l allo-
polypl d f a wh t rye d wheat *Ag opy*
q k gr h h ed part l e no e
y t b e gr w a c mm l le Arti fi
al aut polypl id ha al m le p ll th
t a f r f ge es f r d e e i ta e fr m w ld
fl es t lt t d p es n i ta t
wh h th pec r d t tly r lat d th t th
F i b d l t th rm l d pl d form a e
mpl t ly t le E mples the tra fer f
t re ta f m g at gra (*A g l ps mb l*
lulat) t b d wh t a d f e i ta e t b th
t b e m d bl k ha k d e f *m w ld*
pe f N ti (N *gl ti* N *pl mbag*
f l) t lt ted t ba P l pl dy the
f f lt l pl nt b eed g when mb d
w th h brid zat d lect S BREEDI G
(PL N) GE E GE ETICS PLANT EVOLUTION
SPECIATION [C L S]

B bl g phy B kha N t l Labo tory
G t s in Pla t B d g B kh Symp sia
n B l 9 1956 G L Stebb *I t d*
E l t Pl t 1950

Polypteriformes

A d t cti e d f a ti opt ryg n fi he al



Bichir *Polypterus ... dlcheri* length to 3 ft (*After G A Boulenger Catalogue of the Fresh Water Fishes of Africa in the British Museum vol I 1909*)

cally heterocercal with the upper part continuous with the dorsal fin a dorsal series of free spine like finlets each supported by a radial a distinctive pectoral fin base with three enlarged radials paired gular plates paired ventral lungs and a very large opisthotic

This order consists of a single family the Polypteridae that is known from the Eocene (Cretaceous?) The two recent genera *Polypterus* with about 10 species and *Calamoichthys* with 1 species are confined to fresh waters of tropical Africa Bichirs were long classified with Crossopterygians but they are now believed to be modern descendants of early palaeonisciform actinopterygians *See* ACTINOPTERYGII [R M B]

Polysaccharide

A class of high molecular weight carbohydrates colloidal complexes which break down on hydrolysis to monosaccharides containing five or six carbon atoms The polysaccharides are considered to be polymers in which monosaccharides have been *glycosidically joined with the elimination of water* A polysaccharide consisting of hexose monosaccharide units may be represented by the following empirical equation

$$nC_6H\ O \rightarrow (C_6H\ O_5)\ + (n-1)H\ O$$

The term polysaccharide *is limited to those polymers* which contain 10 or more monosaccharide residues Polysaccharides such as starch glycogen and dextran consist of several thousand D glucose units Polymers of relatively low molecular weight consisting of two to nine monosaccharide residues are referred to as oligosaccharides *See* DEXTRAN GLUCOSE GLYCOGEN MONOSACCHARIDE STARCH

Polysaccharides are either insoluble in water or when soluble form colloidal solutions They are mostly amorphous substances However x ray analysis indicates that a few of them such as cellulose and chitin possess a definite crystalline structure As a class polysaccharides are nonfermentable and are nonreducing except for a trace of reducing power due presumably to the free reducing group at the end of a chain They are optically active but do not exhibit mutarotation and are relatively stable in alkali *See* CELLULOSE CHITIN OPTICAL ACTIVITY

The polysaccharides serve either as reserve nutrient (glycogen inulin) or as skeletal material (cellulose chitin) from which relatively rigid mechanical structures are built Some polysaccharides such as certain galactans and mannans however er e b tl *functions Through the a tion of acids* graded to their constituent monosaccharide units Some polysaccharides yield only simple sugars on hydrolysis others yield not only sugars but also various sugar derivatives such as D glucuronic acid or galacturonic acid (known generally as uronic *acids) hexosamines and even nonsugar compounds* such as acetic acid and sulfuric acid

The constituent units of the polysaccharide molecule are arranged in the form of a long chain either unbranched as in cellulose and amylose or branched as in amylopectin and glycogen The linkage between the monosaccharide units is generally the 1 4- or 1 6 glycosidic bond with either the α or β configuration as the case may be The branched glycogen and amylopectin contain both the 1 4 and 1 6 linkages However other types of linkage are known In plant gum and mucilage polysaccharides 1 2 1 3 1 5 and 1 6 linkages occur more commonly than the 1 4 type

In an attempt to systematize the carbohydrate nomenclature the generic name glycan was introduced as synonymous with the term polysaccharide This term is evolved from the generic word glycose meaning a simple sugar and the ending an signifying a sugar polymer Example of established usage of the an ending are *xylan for* polymers of xylose mannan for polymers of mannose and galactomannan for galactose mannose copolymers Cellulose and starch are both glucans or glucoglycans since they are composed of glucose units

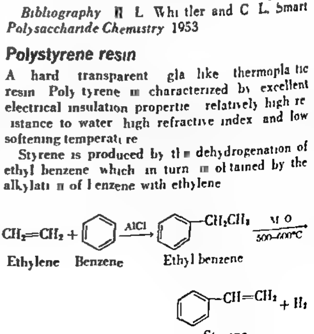
Polysaccharides are often classified on the basis of the number of monosaccharide types present in the molecule Polysaccharides such as cellulose or starch that produce only one monosaccharide type (D glucose) on complete hydrolysis are termed homopolysaccharides On the other hand polysac*charides such as hyaluronic acid* which produce on hydrolysis more than one monosaccharide type (N acetylglucosamine and D glucuronic acid) are named heteropolysaccharides *See* CARBOHYDRATE [W Z H]

Bibliography R L Whistler and C L Smart *Polysaccharide Chemistry* 1953

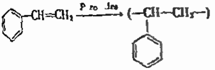
Polystyrene resin

A hard transparent glasslike thermoplastic resin Polystyrene is characterized by excellent electrical insulation properties relatively high resistance to water high refractive index and low softening temperature

Styrene is produced by the dehydrogenation of ethyl benzene which in turn is obtained by the alkylation of benzene with ethylene



Free rad cal cataly ts uch a per xides are ften u d f r polymer zat on and copolymerizati i b lk sol ti a d in aqueous emul i n and us- pe i



The h gh m lecular weight hom polymer c p l m rs d p lyble d are u d a m lding com po nd f r l tr nic m unt ng and in ilat n m g lt b es a d panels For d cu n of copolyme of styren with un aturated polye t r r d th d ying o l e POLYESTER RE INS

The copol m r of tyren and b tad ene wa the j r synthet c rubb of W ld War II During th 1940s the red x system f p lym rizati n wa deve ped n wh ch the pre ence f a red i g gent c ed the per x de to yield fr e rad cal e ap dly at l er temp rat r At the l w r temp tu e f the red x polyme zati n a m r low are polym r c lled c ld rubber l tai ed in h gh e with impro ed phy ical p per t Sty e b t d e c polymers re till u ed in large v l m f r a t mobile t e and n ar rubber arti l S POLYMERIZATIO

H h yr ne-butadiene c p lyme s (c nta ning m e th n 50% tyre) ar e i o rather th n rubbery Th late es a produced by mul o p l ym izat ha ach ed wid age in wate based p nts

By ulf on of the opolym r of ty ene a d d nyl b n insoluble poly l tr lyte s pro- d ed Th pr d t n th f m f st d um alt pl yed a e t i ex hang es which i used for w t softe g

The ff ct f ble d g s all mo nt f a r b- bery p l m s ch s l ut d e ac yl t l r b- ber w th ha d b ittl polyme are m t d amat hen th l tt is p lysty n The polyblend may ha e imp t t ngth gr ater th n t n t m s that f polystyr ne.

Th t e gth of mo ph u m t c p l ty en m b a ed by ld d w g n th ugh cry tallin ty ot p d ced Cold d wn product nth f m of fil m n a d h ets n available

Cry t ll hl ta t p ly tyrene h be n f rmed th p sen e of (1) tr ph nylm thyl po- t m n h xa e sol t n (2) th Alfin c talyst [sod um lly] d m p opo d) i he ne nd be ze l t nd (3) a f egl r c t ly t (t ta r t t hl rid l m m tr thyl) n p tro leum the l e t Th ft n ng tempe t f th ry tall e p lym ub t tally g than th t f th am phou p od t

Bes d s the m ny ppl ati f tyr n n om b t n ith th r mat als bb a d p t la g q a t t of the h mop lym and th pol t) d r mploy d s the inject n mold g toys, p n ls, o lty i m and al the extr n f heet The h ts a e d for p l or they may be fu th h p d b a u m f rming f r u e such a liners f r refrigerat r loor Se PLASTICS FABRICATION RUBBER STYRENE

[J A M L T H]

Polysulfide resins

Re i that ary in p operties fr m s i cou l q iid to r l ber l ke lid Org nic poly ulfide re n ar prepared by the c nd n ati n of organic dil alide with a p ly ulf de

$ClCH_2CH_2Cl$ + Na_2S_4 →
1 D chl ro Sodi m
ethane t tra ulfide

$(-CH_2-CH_2-S-S-)$ + $2NaCl$
P ly ulf l res n

By the u f oth r dichl ride u h a l (hlo- roethyl) ether $ClCH_2CH_2OCH_2CH_2Cl$ the proper ties may l e a ied The c nden at on i u ually n du ted in an queo s med im fr m whi h the prod u t m y l e eparate l and dried Many f the poly ulfide r i s h an od whi h i g n rally cl a a teri tic f mo m ric ulf r comp und l t i u u lly milder n n ture

The l near p lym s can be c l nke l r cured by re t n with zinc x d Compo nd ng and fab- r catio f the rul bery p lymers can be handl d n c n nti n l rubber machi e y The p ly lfide rul be ar d ting i hed l y th r re i t n e to l e t uch a ga ol ne, nd t ygen and o ne The polymers re relati el impe m al le t s Th pr duct re u ed to form chemic lly re t a t ati g a d p al r l b r art cl such as ga l ne bag

The p ly ulfid ubber we e m ngth ery f st mme cial y thet c rubb r Alth ugh the prod u ts are n t s st ng as ther rubl rs thei chem ical r i tance make them u eful n vario appl c tion

The p ly ulfide ul be we e mo g th f r t p l ym t l u ed in l d fuel omp iti n f r r k t Se ORGANOSULFUR COMPOU D POLYMERI ZATION PROPELLANT RUBBER [J A M L M H]

Polytopes regular

The n d m n ional a al g of the eg lar polyg n ($n = 2$) and pl tonic l d ($n = 3$) They re onven ntly den ted by the r S hl fl symbol $\{p,q\}$ for i ta the p t hexago oct g n t t h d n o t hed n re den ted by {5} {6} {8} {3 3} {3 4} The ube i {4 3} bec it fa e ar qu re {4} and the e e 3 f th m at ea l tex Th f e pl t n c l d $\{p,q\}$ which e th bj ct f Eu l d El m ts B ok XIII re d term d by the i eq al ty

$$(p-2)(q-2) < 4$$

Th numbe of t dg f (V E F) a li ted i the t ble a be d du ed fr m tl ob ou elat n $pF = 2E = qV$ with th help of Eule f rmula $V - E + F = 2$

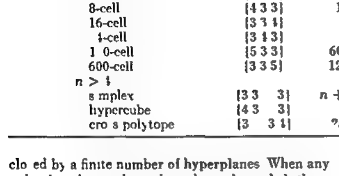
The g n l polytope (met m l o ely c lled polyh d o g rdl s f th mb of d men ns) s fin t r gion f n d m n al p

Regular polytopes in ■ dimensions

Polytope	Schl ıflı symbol	Vertıces	Ed es	Faces	Sol d cells	Hypersol d cell
$n =$						
p gon	$\{p\}$	p	p			
$n = 3$						
tetrat edron	{3 3}	4	6	4		
cul e	{4 3}	8	12	6		
octahed on	{3 4}	6	1	8		
dodecahedron	{5 3}	_0	30	1		
ıcosahedron	{3 5}	1_	30	0		
$n = 4$						
5-cell	{3 3 3}	5	10	10	■	
8-cell	{4 3 3}	16	32	_4	8	
16-cell	{3 3 4}	8	4	3	16	
4-cell	{3 4 3}	4	96	96	4	
1 0-cell	{5 3 3}	600	1?00	7 0	1 0	
600-cell	{3 3 5}	120	720	1_00	600	
$n > 4$						
s mplex	{3 3 3}	$n + 1$	$½n(n + 1)$			$n + 1$
hypercube	{4 3 3}		_ n			n
cro s polytope	{3 3 4}	?n	$2n(n - 1)$			

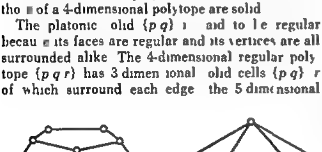
clo ed by a finite number of hyperplanes When any redundant hyperplanes have been dı carded tho e that r main contain $(n - 1)$ dımen ıonal polytope called cells For ınstance the cell of a polygon are ıts sides those of a polyhedron are ıts face and tho ■ of a 4-dımensıonal polytope are solıd

The platonic olıd $\{p\ q\}$ ı aıd to l e regular becau ■ ıts faces are regular and ıts vertıces are all surrounded alıke The 4-dımensıonal regular poly tope $\{p\ q\ r\}$ has 3 dımen ıonal olıd cells $\{p\ q\}$ r of which surround each edge the 5 dımensıonal



(a) (b)

Fig 1 Two reg lar polyhed o s ( ) Dod c hed {5 3} (b) Icosah d {3 5}



( ) (b)

Fg 2 Two eg lar 4-d me o al polyt pe ( ) Th 5-cell {3 3 3} (b) The 8-cell {4 3 3}

regular polytope $\{p\ q\ r\ s\}$ has cells $\{p\ q\ r\}$ s of which surround each plane face and o on

The sıx regular 4 dımen ıonal polytope $\{p\ q\ r\}$ are determined by the ınequalıty

$$p - \frac{4}{p} + 2q + r - \frac{4}{r} < 12$$

The 5 cell {3 3 3} may be drawn ın per pectı e as a pentagon with ıts 5 dıagonal though ın realıty ıts 10 edge are all equal The sımple t drawıng of the 8 cell {4 3 3} consists of an octagon with a square placed ınward on each side The square on two alternate ıdes are easıly visualized a two opposıte face of a cube The 8 such cubes are the cells of the ■ cell

The regular tetrahedron can be ın crıbed ın the cube ın the en e that the 4 vertıces of the former occur among the 8 vertıces of the latter In the same en ■ the cube can be ın crıbed ın the dodecahedron the 16 cell ın the 8 cell the 8 cell ın the 24-cell the 24-cell ın the 600-cell the 600 cell (and also the 5 cell) ın the 120-cell

The vertıces of the n dımen ıonal ımplex {3 3 3} consısts of $n + 1$ poınts all equıdı tant from one another Tho e of the cro s polytope {3 3 4} are at equal dıstances from the orıgın ın both dırectıons along the ■ coordınate axes th u their coordınates (for a cro polytope of edge $\sqrt{2}$) are the permutatıons of $(\pm 1\ 0\ \ 0)$ Sımılarly the 2 vertı es of the hypercul e {4 3 3} of edge are $(\pm 1 \pm 1\ \ \pm 1)$ *See* ANALYTIC GEOMETRY GEOMETRY EUCLIDEAN [H S M C]

Bibliography H S M C xeter *Regular Poly topes* 1948 D Hilbert and S Cohn Vo en *Geometry and th Imagination* 19 2 H P Manning *Ge om try of Four Dimens ons* reprint 1955

Polytropic process

An e pan ı n (or c ntractı n) of a ga during which me heat nt rs (or lea e) the sy tem l ıt not enough to maintain a con tant temperature

D ring the polytropic expan on of a gas, extern l rk is d e both at the e pen e of me de re e m t red internal energy f the y tem and l at th e pen e f th heat tra f rred t the sy t m f i rr d g The p lyt opi patf e m p ed to oth r thermody amic proc es n th e comp ng g aph I mpariso w th the i en tr p p oce lume f ol me the p lytr p c p th ha a h ghe pres re and t mperatu re i e- ca se th add t n l ene gy p ided by th h t t f r pr e See THERMODYNA IIC PROC E S

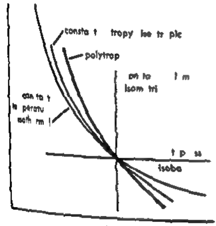
Wh r er ble p lytr p e pan n i pl tted P oord n tes a llu trated th re- t n H wever if the e p n i p l tted l gl g p p th es lt i stra ght l e The m u e l pe of th l e q al the p lyt p e p h h character the xpan Tl

$$P I = P I_2 = \quad ta t$$

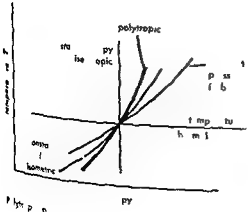
F rth th o k d ne d ring the expan ion proces g n by

$$W \int P d = c n tant \int I^{-n} d = \frac{P I_2 - P I_1}{1 -}$$

wh W is o k d e m f t l b p p nd f ga P ab-ol t pr e in p u d p r qu re f t I pec fi l m n ub feet p r p und nd n



l m



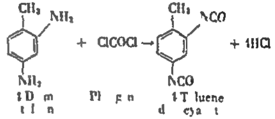
P lytr p p processe mp d t th th m dy m

a on tant for the proc For n xpan n n i l than the val i f th i ntr pic k if l eat i added to the ga whil xpan l ng nd it i great r tl k if h at i t an f rred f m the gas See I ENTROPIC PROCE [J B]

Polyurethane resins

Re in that an l e produ ed in f rm arying fr m hard gl y l ent re tant e att g t al r i n and l t r i ta t r l l er and fle ible or rig l f m Tl e f am ha e f n i tl wid t u in re- c t y ar Tl e fl ible f am ar empl yed a p hol t ry mat i l f fur itur f r rug l cking in sulati n nd cra h p ad The rig d f am are m pl yed a tl e in tr ict ral l minat i l a in airpla wing

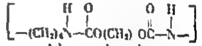
P ly i tl (p ly isocya ate) r m pro- d ce l l y th re ti n f l ocya ate with a c m p und ntain g at l a t tw ti e l dr g n at m h a d l d min r dicarl ylic a d T lu d y nate an l h methyl n di y n te are freq u ntly mpl yed Th y are pr p red l th re t n of p l g ne w th the c rresp nd ing diam e



The nd n ati n f 1 6-h xam thylen d o- y nate th 1 4-b tan diol

$OCN(CH_2)NCO + nHO-(CH_2)-OH \rightarrow$

1 6 H x m th len 1 4-B t ed l
d y t



A l e poly th n

y ld a l ar p l than ha ing e elle t fiber f m g q l t e Th fibers are ge erally m lar t tho f p ly m d h we r th y ha l w fte g p t

P lym f r m g d f ms frequ tly p p d by the t n l t l e d cy te w th a p lye t h g react d —OH gro p F th p d t ff am d p d t dv ntag s t k f th f t th t th i cya t g up w ll re t w th w t r arb yl c a d t y ld c bon d d a d ther an am ne or a am d

$$RNCO + H_2O \rightarrow RNHCOOH \rightarrow RNH_2 + CO_2$$

Ca b m c Am
d

$$RNCO + RCOOH \rightarrow RNHCOOCOR \rightarrow$$

A m ed
a hyd de

$$RNHCOR + CO_2$$

Am l

The amino groups can react with additional isocyanate to form cross linkage. Thus by starting with a polyester having a known quantity of free carboxylic groups as well as free —OH groups, or by adding a predetermined quantity of water to the polyester containing free —OH groups, insoluble cross-linked foams of desired density can be prepared. The foamed products can be cast in place around valves or between the walls of jacketed containers to provide mechanical or thermal insulation.

The flexible polyurethanes may be used for coating rubber articles to give them additional resistance to abrasion and solvents. Wire insulated with polyurethane resin can be soldered directly without previously removing the coating because the polymer decomposes at the soldering temperature to yield a clean wire surface. Among these various applications the uses of the foamed products are developing most rapidly because of the ease of varying the density and flexibility and the good resistance to aging and solvents. *See* PLASTICS FABRICATION; POLYMERIZATION; URETHANE.

[J.A.M.; L.M.H.]

Polyvinyl resins

Polymeric materials generally considered to include polymers derived from monomers having the structure

$$CH_2{=}C\begin{matrix} R_1 \\ R_2 \end{matrix}$$

in which R_1 and R_2 represent hydrogen, alkyl, halogen, or other groups. This article refers to polymers whose names include the term vinyl. Of these polymers several have been used for a number of years, such as polyvinyl chloride, polyvinyl acetate, polyvinylidene chloride, polyvinyl alcohol, polyvinyl acetals, and polyvinyl ether. Indeed the terms vinyls and vinyl resins are frequently used to refer to the first three polymers of this group. Some polyvinyl resins of more recent origin are polyvinyl fluoride, polyvinylpyrrolidone, and polyvinylcarbazole. For discussions of other vinyltype polymers *see* POLYACRYLATE RESIN; POLYACRYLONITRILE RESIN; POLYFLUOROOLEFIN RESIN; POLYOLEFIN RESINS; POLYSTYRENE RESIN.

Many of the monomers can be prepared by addition of the appropriate compound to acetylene. For example, vinyl chloride, vinyl fluoride, vinyl acetate, and vinyl methyl ether may be formed by the reactions of acetylene with HCl, HF, CH_3OOH, and CH_3OH, respectively.

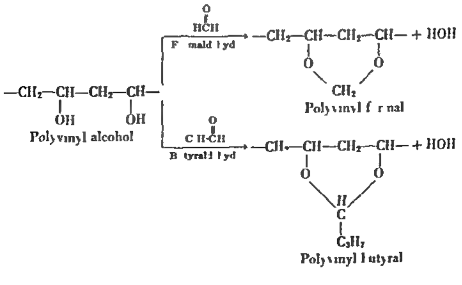
The polyvinyl resins may be characterized as a group of thermoplastics which in many cases are inexpensive and capable of being handled by solution, latex, and injection molding and extrusion techniques. The properties vary depending upon chemical structure, crystallinity, and molecular weight.

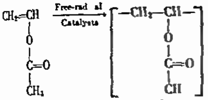
Polyvinyl acetals These are relatively soft, water-insoluble thermoplastic products obtained by the reaction of polyvinyl alcohol with aldehydes. Polyvinyl butyral is soft and rubbery and is used primarily as the inner layer and binder for safety glass. Polyvinyl formal is the hardest of the group; it is used in making light polarizing lenses and films and to some extent in adhesive and wire-coating formulations.

Polyvinyl butyral is usually obtained by the reaction of butyraldehyde with polyvinyl alcohol. The formal can be produced by the same process but is more conveniently obtained by the reaction of formaldehyde with polyvinyl acetate in acetic acid solution.

Polyvinyl acetate Polyvinyl acetate is a leathery, colorless thermoplastic material which often ... relatively low temperatures and which is relatively stable to light and oxygen. The polymers are clear and noncrystalline. The chief applications are as adhesives and binders for water-based or emulsion paints.

Polymerization and copolymerization may be conveniently effected by free-radical catalysis in aqueous emulsion and suspension systems. Vinyl acetate copolymerizes readily with various other vinyl monomers; however, it does not copolymerize with styrene by the free-radical process.





\ yl cetat P lyv vl cet te

A h d o sold p lymers nd c p lymer m y be ed d rectly i hewi g g m and in dhe e f rm l t

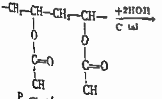
Aq eou di pe n s produced by the em l i n polym zat on proces d commonly called p ly er em l r latice ar u ed f r treat g t xt les a d pap adhe a d a water based pa t

The t r ba ed pai t p ep ed by p gme t ng n l cetat p lym d p lymer em l i n ha e a hieved wide u age beca e of low c t f f l m f applicati n nd re i t nce to b ri g

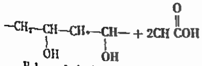
A te em ed fr m the latex by evap tion r b pti the su pended p lymer p t le co lesc i t a t ugh film Th ch ract r f the m may b mod fied by the u e f m n m in th m al polym zatio or by the add tion f p st ze s t th fi l emul io

Polyvinyl alcohol P lyv yl l h l i a to gh h t h pol m h h n be formed i t tr ng fil s t b and fiber th t a e highly re i t t to h d oc bo l ts *Although* p ly nyl alc h l h e f th few w t s l bl p lym it can b end red i l bl in water by drawi g r by the u e f l nk g ts

So f t yl al h l t elf CH =CHOH ha n t bee isolated r act de gn d to p d the m m y ld th t t mer cetaldehyd m t d H eve the p lym n be p od ced o a e m m l sc le by the hyd ly f p lyvi yl a etat



P yv yl c tat



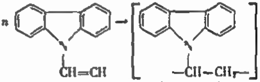
P ly nyl lc hol A t c c d

T p f p du t r al bl th e f rmed b th e t ally omplet hyl l f m d by i mpl te hyd ly (50-90%) f p lyv yl t t a d th Th f rme the mpl t ly hyd ly ed p d ucts m b pl t c d w th w t gly ol d m ld d t d d t film d tube d fila ment wh h t t t hyd c rb a d can

le nd red in l l l t wat r l y c l l drawing or heat r b the u e f chemical c l nki g ag t On ld iraw ng th l g ee f cry tallin ty i ib tant lly i r a ed Th pr l ct are u d f r h rs i ga l e l e f r grea e re i tant c ting a d p pe all e i f r treati g paper a d t xtiles and a m l f s l th kener In l l l zed fib e s l a e f un l larg u e in Japan f r l ti ng and trial fal ric d c r lag

The partially hydr lyzed pr d i t are gen erally m re water lul l nd l ul j t t ry tallizati n by d awi g Th es mate al are d a emul ify ng agent and thi k ne i teel quen h ing l ts i adl esi e f rm ilati and in textile si es

Polyvinyl carbazole P ly inyl carl z le i a t gh gla y th rm pl tic with x ell t electr al pr pe tie and th r lati ly higl ft g t mperature f 1 0 150 C. P lyme i ati n n l carried t in l lk l y fre d cal c taly U es



V vl carba le P lv i l carba le

f the prod t are l mit d t p c l electrical appl ati req ring t to m de t ly high t mper t re

Polyvinyl chloride Polyvi yl cl l ide i a t ugh st o g the m pl t m t r al whi h h a e cel lent mi ti n f physi l d el ct ical p p tie The pr d cts u l ly l ar terized a pla ti d ig d type

The pl t iz d type e the ft c polymer or pla t zed l m p lymers a la t mat l which re fam l r in th f rm f h er rtain fl er g ra n at di hp d ll b ttle t p l p th t c f m nd p kag g film m ng th

R g d p lyvinyl chl ride prod ct wl i h may si t f the h mopolymer copolymer or p ly bl d a mm nly d i the ma f ct e of ph gt ph rec d p pe chem ally e i tant i n r f hemi l t l d f r w e t g

Th m m r f q e tl pr p d fr m hlo ne tyl ne d thyl by omb at n of pr e wh h ff d mpl t t l ti n f tl H l e

$$CH_2{=}CH_2 \xrightarrow{Cl_2} CH_2Cl{-}CH_2Cl \rightarrow CH_2{=}CHCl + HCl$$

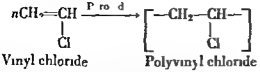
Ethyl n l D hlo th V yl chl d Hy d o g n hlo r d

$$CH{\equiv}CH \xrightarrow{HCl} CH_2{=}CHCl$$

A tyle V yl chlor de

Th p lym t f yl hl de nd n p lyme zat w th oth i yl m om s may

be initiated by peroxides and are conveniently



carried out in the presence of chain transfer agents in aqueous emulsion or suspension systems

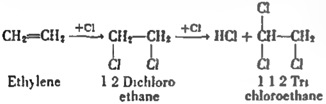
Because polyvinyl chloride products have a tendency to lose hydrogen chloride at high temperatures a stabilizer such as calcium carbonate is usually included in the final composition

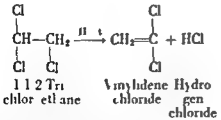
Blends or alloys of polyvinyl chloride with small amounts of rubbery materials such as the copolymer of butadiene and acrylonitrile have been produced for applications such as panels and pipe in which impact resistance as well a hardness and strength is desired

Polyvinylidene chloride Polyvinylidene chloride is a tough horny thermoplastic with properties generally similar to those of polyvinyl chloride In comparison with the latter polyvinylidene chloride is softer and less soluble it softens and decomposes at lower temperatures crystallizes more readily and is more resistant to burning

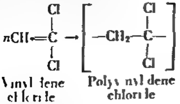
Because of its relatively low solubility and decomposition temperature the material is most widely used in the form of copolymers with other vinyl monomers such as vinyl chloride The copolymers are employed as packaging film rigid pipe and as filaments for upholstery and window screens

Vinylidene chloride is normally prepared by the pyrolysis of 1 1 2 trichloroethane The latter is obtained by the chlorination of 1 2 dichloroethane which in turn is formed by the addition of chlorine to ethylene





Polymerization as well as copolymerization may be initiated by peroxides and other free radical



catalysts and is most satisfactorily effected by emulsion and suspension techniques

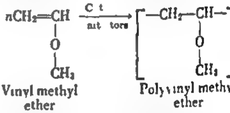
Because of the relatively low decomposition temperature of polyvinylidene chloride a stabilizer such as an amine is normally included in the composition

Films of polyvinylidene chloride and especially the copolymer containing about 15% of vinyl chloride are resistant to moisture and gases Also they can be heat sealed and have the property of shrinking on heating By warming a food product wrapped loosely with a film of the polymer a skin tight tough resistant coating is produced

By cold drawing the degree of crystallinity strength and chemical resistance of sheet filaments and even piping can be greatly increased

Polyvinyl ethers Polyvinyl ethers exist in several forms varying from soft balsamlike semisolids to tough rubbery masses all of which are readily soluble in organic solvents Polymers of the alkyl vinyl ether are used in adhesive formulations and as softening or flexibilizing agents for other polymers

The monomers may be prepared by the reaction of alcohols with acetylene in the presence of alkali Polymerization may be effected in bulk or solution at temperatures of -100 to $+25$ C by use of cationic initiators such as boron trifluoride By

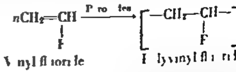


careful choice of conditions it is possible to achieve stereoregular polymerizations which yield partially crystalline polymers that are harder and tougher than the amorphous products

Polyvinyl methyl ether is soluble in cold water but precipitates when the temperature is raised to about 35 C The other alkyl vinyl ether polymers are insoluble in water

Polyvinyl fluoride Polyvinyl fluoride is a tough partially crystalline thermoplastic material which has a higher softening temperature than polyvinyl chloride Films and sheets are characterized by high resistance to impact and cracking caused by flexing and temperature and to weathering

Polymerization can be effected in the presence of oxygen and peroxidic catalysts Because of the low boiling point (−88 C) and high critical tempera



ture of the monomer polymerization is accomplished by use of pressure techniques similar to those employed in the high pressure process for polymerizing ethylene Like other polyvinyl halides polyvinyl fluoride tends to lose the halogen acid at elevated temperatures

Comm r i l pr d ct o ha j t l een in tiated a d t seems likel th t films and fil ments l p ly no l fi r de ill find many appl cat

Polyvinyl pyrrolidone P l vi yl p r li l ne i a at r soluble polymer of l i nat re whi h ha fil f rm g propert e tro g al pt or c m pl xin q lit fo ar iu reag nt and the abilit to form at r oluble alt wh ch are p ly l trol t The polymer ca b prepa l l y fr e-

radi al polyme izat o in b lk or aq teo s l it n bst me sol ti s we e sed i C rmany in W rl l W ll a s e t d f l lood pla ma Tl e m n current uses are wate l l liz g ag nt f r med ci l age ts such s i d e and a em perma ent sett ng agent in h p av Certain sy ete te t le fibers c nt ning sm ll amou t of m lpyrr l d e a pol m r ha e impr ed affin t f dye

New resins New polyv yl re in ar made a labl ften in the f rm of p lymer when effective mbi ti f mon m prepar t polymerizat n m th d nd p perty r lat n hips ar devel ped F r e ample s yl ? thyl her te, nyl lea d nyl te rate are ir rentl being u d e p lym on th th r h nd, th h m polymer of vinyl t arat a wa y bstan e empl yed i w x f rm l t a d a a l th r tre t g ag t It l kely th t new p l m l res ll be m k g the r way i t mm n u r a pe iod f ma y y ars S PLA TI TERSE TIO POLYMERIZATIO POLYMER PROP ERTIES

[J A M L M H]

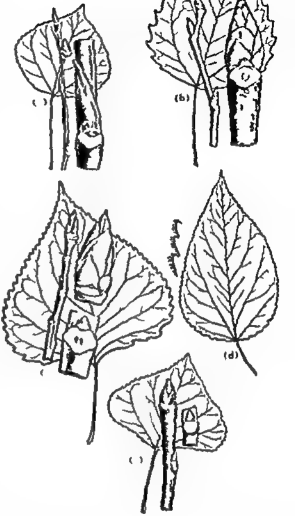
Pomegranate

Sm ll d d t n of the pecie Pu i a gra m, bel g g to th pla t order Myrt le P me grana g own in an me tal as well for its fru t, Pr p g ti n by tt g a d i n lly by la er g Th f meor t i a t e of A i h g been d c b d by wr t a ly a 300 s lt w gi ll k own for it m d in l q al bee d eur f a s ill we tt b t d to tl fru t, w the nd a d th ba k f the oot Th fru i redd h p m l k B ry nt i ng n ec d mb dd d n r m n p lp f m h h a d edd h j may be bt ed Limi d qu nt t e re g i Cal f n d th Gulf St t S FRUIT (TREE) MYRTALES STEM CUTTINGS

[J H C E]

Poplar

A g n P p lus of th w llow f m ly h a t r nd b mpl It at l a wh h e ally t ader th n th f the w ll w th th Ame i ca p sent i f th f m ly (e WILLOW)



(a) Q ak g p e t mbl g pe P p l s t mu- lo d (b) B gto th p B g dd l t ( ) Cot to w d ckl popl r P d lt d (d) B l am t am h p pl P b l m f ( ) L mb dy p pl P n t l

P p l rs h a aly b d l tt r b k ll we s nd f it tk d S gled p th

S me pe e re mm ly call d tt nw d be f the tt y h tta h d t the eeds Othe n lled a pen ha e we k fl tte d leaf t lk wh h th lea t fl tte i th l ght t bre O f th mpo t nt p i i th U ited St te i the q aki g a pe P tremu lo d s which att n a h ght f 90 ft n tl R k s b t m ll the F t Th tr w d l d t ib t d N rth Ame a from Lab do t Al k In the W t t t d th th gh th R ck nd Cal f n a t N w Me c nd Low r Cal f n a a d the ea t rn U t d State n gr w a fa y th W t V g n a It dily r g d by ts omp r ti ly m ll finely to thed lea a d b the h y p t d w nt b d The ft wood f thi p c s u ed f pa

per pulp several million board feet are cut annually. *P. grandidentata*, the bigtooth aspen, attains a height of 60–70 ft and occasionally a diameter of 2 ft. The bigtooth aspen has a more restricted range in the northeastern quarter of the United States. The leaves are usually of larger size, 2½–4 in. long, and have larger teeth, hence the common name. The buds are plumper and somewhat downy.

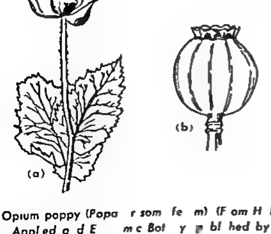
The European aspen, *P. nigra*, which is similar to the quaking aspen, is sometimes planted, and its variety *italica*, the Lombardy poplar of erect columnar habit, is used in landscape planting.

The black cottonwood, *P. trichocarpa*, is the largest American poplar and is also the largest broad-leaved tree in the forests of the Pacific Northwest. It attains a height of 175–225 ft and a diameter of 7–8 ft. This tree ranges from southern Alaska to California and eastward through Washington and Oregon to Idaho, Montana, and Nebraska. The hairy fruit of the black cottonwood is a 3-valved capsule.

Populus deltoides, native in the eastern half of the United States, is a fast-growing tree which usually attains 80–100 ft in height and 3–4 ft in diameter, but under favorable conditions in the Mississippi Valley it may attain a height of 150 ft and a diameter of 7–8 ft. The leaves are broadly triangular, hence the specific name, and the large terminal buds contain a pleasant-smelling balsamic resin. In *P. balsamifera*, the balsam or tacamahac poplar, the resin is used in medicine as an expectorant. The wood is used for veneer, boxes, crates, furniture, paper pulp, and excelsior. It is also planted as a shade tree and used in shelter belts. *See* FOREST AND FORESTRY; TREE. [A.H.G.]

Poppy

A plant, *Papaver somniferum*, which is probably a native of Asia Minor. It is now cultivated extensively in China, India, and elsewhere. This plant is the source of opium, obtained by cutting into the fruits (capsules) soon after the petals have fallen. The white latex (juice) flows from the cuts and hardens when exposed to the air. This solidified latex is collected, shaped into balls or wafers, and often wrapped in the flower petals. This is the crude opium, which contains at least 20 alkaloids, including morphine and codeine. These drugs are used in medicine to allay pain, induce sleep, and relax spasms. Opium is one of the most useful drugs, but it is habit-forming and consequently should be used with the utmost caution. The opium habit is deleterious physically, mentally, and morally, and misuse of the drug is an extremely serious problem. *See* PAPAVERALES. [P.D.S.]



(a) Opium poppy (*Papaver somniferum*). (*From H. Kraemer, Applied and Economic Botany, published by the author, 1914*) (b) Capsule of poppy. (*From W. E. Loomis and C. L. Wilson, Botany, rev. ed., Dryden, 1957*)

Population dispersal

The process by which groups of living organisms expand the space or range within which they live. Because of their reproductive capacity all populations have a natural tendency to expand. An increased area supports more individuals; dispersal and reproduction are intimately correlated.

Distinction should be made between dispersal and seasonal migration. Birds, butterflies, salmon, and others migrate regularly without necessarily expanding their geographic range, since they usually return to their original area or die out.

Dispersal phases Dispersal consists of several phases: (1) the production of units that is, of individuals or parts of individuals (disseminules) fit or adapted for dispersal; (2) the transportation of individuals or disseminules to the new habitat; (3) ecesis, the process of becoming established through germination, rooting, physiological and psychological adjustment.

Dispersal units These are disseminules (propagules or diaspores) which may represent various stages of the life cycle of the individual. Many free-living animals do not produce special dispersal structures but rely upon the ability of the entire organism to move about (vagility). Organisms attached to a substratum, as most plants and certain animals, produce disseminules adapted to certain agents of dispersal. In order to be effective, a disseminule must have the ability to develop into one or more complete individuals. The structures listed in Table 1 are examples of disseminules. Sperm cells, unfertilized eggs, and pollen grains, although capable of migration, are not true disseminules because they cannot give rise to new individuals.

It is possible to analyze plant communities on the basis of morphological features of the disseminules. By assigning species to dispersal types one can construct dispersal spectra comparable to life-form spectra in purpose and in usefulness.

Transportation Individuals or disseminules are transported in five general ways: self-dispersal (autochory), water dispersal (hydrochory), wind dispersal (anemochory), animal dispersal (zoochory), and dispersal by man (anthropochory).

In active self-dispersal (autochory) the organism spreads in the course of its normal activities. The flight of starlings resulting in their gradual spread through the United States ... tility of ...

T bl 1 Ex mpl f d pers l stages in lif cycl of pl ts d a m l

E vironmen	Org sm	D seem l	D persal by
Sea bo tom	K l	Zoospor	C rre
	Cor l	Pl l	C rre
	Sea orm	Troch phor	C
	Cl m	Trochoj h	C rr
	B rna l	Ad l	D f o l h pe
	Crab	Zoe	C rr
	Se rch	Pl es	C ts
	F h	Ad l	A tochory
	La rey	Ad l	F h
Terrestrial	M shroom	pore	W nd
	F	ior	W nd
	Pi	Seed	W nd
	Pl berry	Fru	B l
	T mbl eed	F re pl t	W l
	Inser	Ad lt	A hory nd
	d	Yo ng m l	W nd
	B les birds, m m- m l	Ad l	A ochory
Parasitic	Bacte	En cell	W fond t
	I es nal ba	C t	W food m
	M lari para	C m pocosoit	Mosq
	T pe orm	Eg	Pi
	Blood fl k	Eg cere	W na l

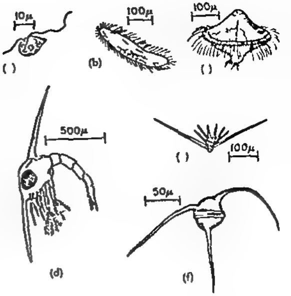
T bl 2. Pl t d pers l types b sed upon morph l gical d pt ti

Y	D f tı	E mpl
Sarcoch es	D ss m les fleshy	Ch rry
Desmochores	D ssem les t ky b bed	Cockl b
poroch es	Dissem les m te, b ht	F rn
P gonoch es	Dissemi les pl med	M lkweed
Pteroch es	D ssemi les w ged	M pl
Cy locho es	Sph ri l f m w k	T mbl weed
B llocho es	Sh t w y by p re t pla t	T l m t
A och es	D pos ted by pa t pl t	W lk g f
Scleroch es	D ssemi al w th t p- p t d ptati	V l t
B roch es	Diss m les h y	O k

es lt g a grad l spread through th nm e t med e mpl Certai pla t po e mecha ms f lf d sp al s u h es nd b lloch l st d n T bl 2 I pa d pe al o r m g ts rry the d p l t t new loc n S ch ge ts to are wate ts and m l y f m n h l h a train th p a d pl es

Wat d p l hyd h ry s prev l nt all m ri a d th aq at p p lat Pl kt n u lly nta larv l f m f b tt m-dwelle (F g 1) T rre t l f rms a t d w th hore hab tats c mm nly d p ed by w t B oy s cy d ta e t ltw t D q s t f oc dı p l The fi t de of w ı l d h K k ta oft n f th typ T soce m l t n fl nd f be n pla ned p rtly by rre t

W d d pe l, a m h ry ha o effect lt m es W g d m le pen d t d gr l d (y l h es F g) ıt deff t f fl ing ged d m J (pt h r F g 2b d) d ıt es l ghtw ght sp s nd d em



F g 1 Ds m l l pl kt ( ) K lp oo po (b) Co l pl l ( ) W m t o h ph (d) C b o ( ) B ttl t pl t s (f) C l m t po

n l w th pl me f great dı t es (p r h res d p g n cl re Fig ? h) In e t p d r a d th l ght ımal h e b n f d m mile ı th aı t g the w th p pl r seed and ther d em ul (F g 2f g) Th s tl ey m y be rt d f nd d f m l

An mal d per l z och ry ı d ded ınt pı z h y (b b d r st ky dı min ıle d m chores F g 3a b) and nd ch ry (d em nul e te a d ege t d by n mals) D min le ad pt d t end ooch are th a l ke rillate eed (Fig 3d) mm ın the t opics and fruits with fl hy me ocarp (F g 3f g) S rvı al ın the d ge tı e t t of ımal a prereq te Bright frı t l are f q ent

D pe l by m anth p h ry ın ol es pur posely drop sed gam m h as d me treat d an m ls d pla t and tho e de t lly t ans po t d su h as we ds alo g r lr ds leetles ın gr h pm nts b d ats b cl d starf l n a d n hıps

Ece s S ı p p l t d p l depend po th e f ct rs f tne f th new hab t t fit nes f the m grat g d d al d the cha e f the j t p tı n f th tw wh h ın th long n d p nd the number of ı dı d l ın ad g th w hab tat The pr bab l ty f r w hab tat t be f abl t t cl e to th p rent popu l t Sp bl wn g t dist c s h e l s ch e f l d g ın sp ts s t d f ge m at tha ha seed f ll ng l e to the pa t pl nt I w de- a g dı p l l g numb f d sem n le ally ry th n at l e r nge to s

Th fit f th d d ls dep d p rtly pon the g et m ke up Off p g of g ms that p d e w th t l ı (p m st) e l k ly to s c ed o ly n ıd t l h b t t a nh d d d l d m l

per pulp. Several million board feet are cut annually. *P. grandidentata*, the bigtooth aspen, attains a height of 60–70 ft and occasionally a diameter of 2 ft. The bigtooth aspen has a more restricted range in the northeastern quarter of the United States. The leaves are usually of larger size, 2½–4 in. long, and have larger teeth, hence the common name. The buds are plumper and somewhat downy.

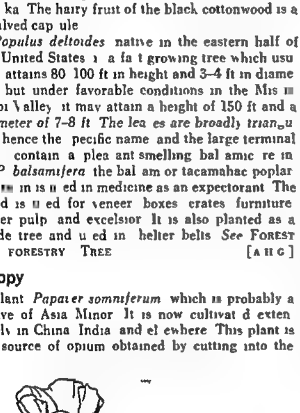
The European aspen, *P. nigra*, which is similar to the quaking aspen, is sometimes planted, and its variety *italica*, the Lombardy poplar of erect columnar habit, is used in landscape planting.

The black cottonwood, *P. trichocarpa*, is the largest American poplar and is also the largest broad-leaved tree in the forests of the Pacific Northwest. It attains a height of 175–225 ft and a diameter of 7–8 ft. This tree ranges from southern Alaska to California and eastward through Washington and Oregon to Idaho, Montana, and Nebraska. The hairy fruit of the black cottonwood is a 3-valved capsule.

Populus deltoides, native in the eastern half of the United States, is a fast-growing tree which usually attains 80–100 ft in height and 3–4 ft in diameter, but under favorable conditions in the Mississippi Valley it may attain a height of 150 ft and a diameter of 7–8 ft. The leaves are broadly triangular, hence the specific name, and the large terminal bud contains a pleasant-smelling balsamic resin. In *P. balsamifera*, the balsam or tacamahac poplar, the resin is used in medicine as an expectorant. The wood is used for veneer, boxes, crates, furniture, paper pulp, and excelsior. It is also planted as a shade tree and used in shelter belts. See FOREST AND FORESTRY; TREE. [A.H.G.]

Poppy

A plant, *Papaver somniferum*, which is probably a native of Asia Minor. It is now cultivated extensively in China, India, and elsewhere. This plant is the source of opium obtained by cutting into the fruits (capsules) soon after the petals have fallen. The white latex (juice) flows from the cuts and hardens when exposed to the air. This solidified latex is collected, shaped into balls or wafers, and often wrapped in the flower petals. This is the crude opium, which contains at least 20 alkaloids, including morphine and codeine. These drugs are used in medicine to allay pain, induce sleep, and relax spasms. Opium is one of the most useful drugs, but it is habit-forming and consequently should be used with the utmost caution. The opium habit is deleterious physically, mentally, and morally, and misuse of the drug is an extremely serious problem. See PAPAVERALES. [P.D.]



(a) Opium poppy (*Papaver somniferum*). (From H. Kraemer, *Applied and Economic Botany*, published by the author, 1914) (b) Capsule of poppy. (From W. E. Loomis and C. L. Wilson, *Botany*, Dryden, 1957)

Population dispersal

The process by which groups of living organisms expand the space or range within which they live. Because of their reproductive capacity, all populations have a natural tendency to expand. As increased area supports more individuals, dispersal and reproduction are intimately correlated.

Distinction should be made between dispersal and seasonal migration. Birds, butterflies, salmon, and others migrate regularly without necessarily expanding their geographic range, since they usually return to their original areas or die out.

Dispersal phases. Dispersal consists of several phases: (1) the production of units, that is, of individuals or parts of individuals (disseminules) fit or adapted for dispersal; (2) the transportation of individuals or disseminules to the new habitat; (3) ecesis, the process of becoming established through germination, rooting, physiological and psychological adjustment.

Dispersal units. These are disseminules (propagules or diaspores) which may represent various stages of the life cycle of the individual. Many free-living animals do not produce special dispersal structures but rely upon the ability of the entire organism to move about (agility). Organisms attached to a substratum, as most plants and certain animals, produce disseminules adapted to certain agents of dispersal. In order to be effective, a disseminule must have the ability to develop into one or more complete individuals. The structures listed in Table 1 are examples of disseminules. Sperm cells, unfertilized eggs, and pollen grains, although capable of migration, are not true disseminules because they cannot give rise to new individuals.

It is possible to analyze plant communities on the basis of morphological features of the disseminules. By assigning species to dispersal types, one can construct dispersal spectra comparable to life-form spectra in purpose and in usefulness.

Transportation. Individuals or disseminules are transported in four general ways: self-dispersal (autochory), water dispersal (hydrochory), wind dispersal (anemochory), animal dispersal (zoochory), and dispersal by man (anthropochory).

In active self-dispersal (autochory) the organism spreads in the course of its normal activities. The flight of starlings, resulting in their gradual spread through the United States, and the motility of la

T ble 1. Exa ples f di persal stages in lif cycl
of plants d mals

Environmen	Or nism	D m m l	D persal by
Sea bottom	K l	Zoospore	C rre
	Cor l	Pl l	C rre t
	Se orm	Troch hore	C rr
	Clam	Troch hore	C rre
	Barnacl	Ad l	I ft on l h ps
	Crab	Zoe	C rr
	Se rch	Pl es	C rr ts
	Fish	Ad l	A orchory
	La prey	Ad l	F h
Terrestrial	M sl room	pore	W nd
	Fern	por	W l
	Pi	Seed	W nd
	Bl berry	Fru	B rd
	T mbl eed	Ent pl	W l
	Insect	Ad l	A achor nd
	Spi ler	You m l	W nd
	Rep les, bird m m l	Ad l	A torhory
Parasitic	Bac eri	E cell	W fond
	I es nal ba	C	W fond m
	M lari pa	G m t porozoi	Mosq to
	T peworm	Egg	Pi
	Blood fl k	Eg cercari	W l

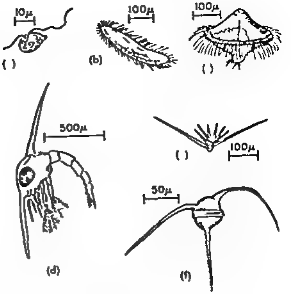
T bl 2. Pl nt d pers l types based
upon morph log cal d ptati

	D fi tı	Ex mpl
Sarcochores	D ssem les flesl y	Ch rry
Des ochores	Dissem les t ky ba bed	Cockl b
Sporochores	D ssem les m te, light	F rn
Pogonoch res	Dissem l pl med	M lkweed
Pterochores	Dissemi les w ged	M pl
Cyclochores	ph l fram w k	T mbl weed
B lloch res	Sh t y by p t pl t	T l me- t
Autochores	D pos ted by p t pl t	W lk g f rn
Bel roch es	D ssem l w th t p- pare t d pt ti ns	V l t
Barochores	Dissem les h y	O k

t na res lung in gr d l p d th ough the n tri ent med a e x mpl Ce ta pla t p mech ni m f elf-d p sal as uxo hore d b lloch es l ted i T bl 2 In p ss e d pe l o m g nt i rry th d p r l t to a ew loc t n Such ge ts o ct e w te current d. m l f m n h l s s li s trans sh ps, a d pl ne

W t d p l o hyd och ry is p ev l t n ll m rin d th aq t p p l ti Plankt u ll ont larv l f rm f b tt m dwell r (F g 1) T rest al f rm c t d w th h e h b tats a e mmonly d sper ed by w ter B y ancy nd re t n e t lt w t r p eq te f oc a d p al The fi t i de f ew land h a Kr k t r ft n f th typ T oc a m l r tie n fi r d f s ha been pl ed p tly by t

Wind d pe al m hory h v eff t h m es ll g d m l i p d ert d gr l d (y loch es Fig) t d fle t f ll ing inged d em ules (pt h i F g 2b c d) d t carr tw ght p d di m



Fg 1 D m l t pl kt ( ) K lp oo p (b) C l pl l ( ) W m t ch ph (d) C b ( ) B ttl t pl t (f) C t m t po

nul with pl m f g at di ta es (p r h re a d pog och res F g 2e h) In e t p de d tl light a mal h b en f i d m y mile in the a t geth with p pl i eed a d th d s min le (Fig 2f g) Thu they may l arried h dred f m le

A m l di pe l z och ry d d d i t pi ochory (barbed o t ky d eminule de mo- h res F g 3 b c) a d d hory (d m l eaten d ge ted by a m l) D eminules ad pted t e d o h y are tho e like ar ll te eed (F g 3d) c mm th tropic d fruits w th a fl hy mes c rp (F g 3f g) S rvi al in the d ge t t t f an m l i e equisite B ght f it col s f q ent

D pe al by ma thropo h ry l es p p ly d pe ed o g n ms s h a dome t cated n mal and pl t d tho acc dentally tra p t d ch as we d l g ailroad beetl i g n shipme t b d t b rnacle d sta fi h and in sh p

Eces S p p l t n disp l d pend pon th e f t s fit f the n w hab t t fit n f th migrating indi id ls and the cha ce f th j t posit n of these tw whi h in the l d pe d n the mber f i di id ls i v d g the new h b t t Th p obab l ty for ew hab tat t be f abl g e t clo t the p re t p pu l ti n Spo e bl w g eat d t n s h e le s ch n f l d g n p t ted f g mi ti n th h e d fall g lo e t the p e t pla t In w de ge d p r al l ger n mb of d semi n le usu lly ry than at l r nge t s s

Th fit ess f th d id l d pend p tly upo the r g n t m ke up Off p ng f g n m that p d with ut l (p m t) i l k ly t suc d ly d ti l hab tat a ph d da d l s d m la g sm Off

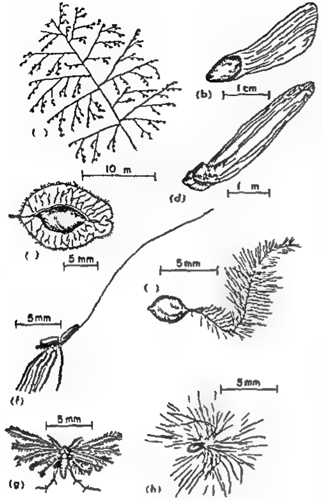
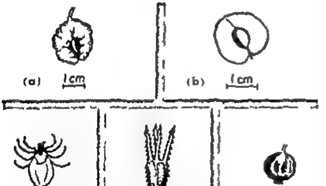


Fig 2 D ssem nul s d spe sed by w d (a) Pan c g ass (b) P ne eed (c) Elm samara (d) Tul p tree ca pel (e) Cl mat ca pel (f) Sp d r (g) Moth (h) Cottonwood



F g 3 D ss m ules t a sport d by an mals ( ) A l late l gume s ed (b) Che ry (d upe) (c) T ck (d) B g ga s t ck f u t ( ) C a t be ry (f) Sandb sp kel t (g) Jun p r co e

pring from elf or cro fertilizing parent may succeed in a variety of ituations However some hybrid which are exually terile are known to perpetuate them elves through apomixi These are usually very successful locally

Barriers to dispersal A barrier i any discon tinuity in the habitat greater than the maximum di tance traveled by organisms in their normal di per sal Oceans eparating terre trial habitats c nti nents separating marine habitats mountain ranges intercepting w ind di per al and de ert interrupting the continuity of forested land are all effective major barrier Through the intervention of man these barriers are broken down in many ca es Since the de elopment of frequent world travel thou ands of pecies have become e tabli hed on new continents as a re ult of anthropochory *See* PARTHENOGENESIS POPULATION DISPER ION SPE CIATION [K LF]

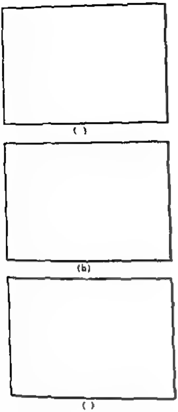
Bibliography P Dan ereau and K Lems The grading of disper al types in plant communities and their ecological ignificance *Contrib inst botan univ Montr al* 71 1957 P A Fryxell Mode of reproduction of higher plants *Botan Rev* 23 135–233 1957 P A Click *The Distribution of Insects Spiders and Mites in the Air* USDA Tech B ill 673 1939 R Hes e W C Allee and K P Schmidt *Ecological Animal Geography* 1937 E J Sal bury *The Reprodi ctive Capacity of Plants* 1942

Population dispersion

The spatial di tribution at any particular moment of the indi idual of a specie of plant or animal Under natural condition organi m are di tril uted either by acti e movement or migration or by pa sive tran port by wind water or other rgan i m The act or proce s of di emination i u ually termed di per al (*see* POPULATION DI PER AL) while the re ulting pattern of distril ution i be t referred to as di per ion Di per ion i a ba ic characteri tic of population c ntrolling vari u feature of their tructure and organizati n It determine population den ity that i the numb r f individuals per unit of area or vol ime and u re ciprocal relation hip mean area r the averag area per individual It al o determine th fre quency or chance of encountering one or m re in dividual of the populati n in a particular ample unit of area or vol ime The ecol gi t therefore tudie not only the fl ct iati n m n mb er f in dividual in a population b t al the changes in their di tributi n in pace

Principal types of dispersion The d p r i pattern of indi id ial in a populati n ma c nf rm to any one of e eral broad type such a rand m uniform or contagi u (cl im ped) Any patt rn i relati e to the pace b ing examin d a popilat n may appear clumped wl en a larg area i c n si l red l ut may pr ve t b di tril uted at ran l m with r pect to a mu h mall r r a

R nd m or haphaz rd d p rsi n Th i imple t that th indi i lual ha b en di tril ted b chan In u h a di tril uti n th prol al ility f fi di g an in l i lual at any point i th ar a th



1 Th p tt m f th d p rs of d ual p p l t ( ) U f m (b) R d m Cl p d b t g p d m (E P Od m F d tals f E l gy S d 1953)

ne f all po t (F g 1b) H t ly d m tt m ll d l p ly f h d id l h h d q l nd d p d nt pp t ty t e t bl h elf t a y g e p t In d mly d p d pul ti th l t h p b tween freq ency d ty n be p ed l y th f mul

$$F = 100(1 - \quad)$$

he F i p t g f qu ey D s d ty d is th b e f t l N p l g thm h res f d mly ele t d mpl s t k f m p p l t wh nd d al re pe ed at d m the umb f mple on i 0 1 2 3 d d l f rm t i llk P s d tr but

$$D\,e \quad \frac{D^2}{2} \quad D\,\frac{D^3}{3!} \quad - \qquad \frac{D}{} \; -D$$

l d mly d p d p p lat h the f th h t t th t th d n t pl e f l ted t th d t b tw n d d ls w th h p p l t the f ll w g w y

$$D = \frac{1}{4^2}$$

her th m d t e b twe n n d d al d t n t gl bo Th m them t l p b f a qu t t t t dy f p p l t d persion (BIO TRICS) F mpl f pp

mately ran l m d per o can l e f nd in the pat tern f ettleme t l y fr e fl ting marine larvae and f col izati n f l r gr l l y airl r e di em nule of plant Ne rth l true ran l mne appe t be rel ti ely rare in natu and the maj rity f p p l ti n l part f m it tler i tle d rect f f rm paci g of i li i lual r m e ften n tl e d e ti n f aggregati n

Unifo m d spe s n Th type f di tril uti im pl s a reg larity f di t e betw an l am g the i d idual f a p lati n (F g 1) Perfect unif rmity e ts wh n tl d ta e fr m ne in d d al t t neare t neigl l r i tl e me f r all divid l Th ach l n a pla e u f e o ls when tl i d id l are a ged in a h ag l patter Patt appr ach g unif rm ty are m t l i u in the di pe n f rcha d tre and i ther art f l plant g l t th te d s t a regula d tr l i t i al f d in nat re a f r e mple in tl relati ely e paci g f tree in f rest ca p e the geme t f h l i d se ert d the d t l ti f te r t l m l

Co t g s r cl mp d lispe s on Tl m t f e q e t t pe f d tribiti n e unte ed c nta g o l mped (F g 1c) indicating the exi t e f agg g t ns e g ap i tl e pop l ti n Clu t a d cl e f pla t d fam l es fl k d he d f imal ar c mm n then me a Tl d f agg g t m range fr m l oo ly e n ne ted g p f tw th e i d dial t l g mpact w m mp ed of all the m mber of th local p pul t F tl m tl f rmati n f g p troduces a h gher de f mplex ty i the d p pattern si ce th eve al agg g t n m y th m l es b d i b ted at d m l or l mp An d q te de pt n f d per i n the ef e m i t ncl id t nl the de t m t of the type f di t b t h t al o n e m nt f tl exte t f gg gat n if th l tt r pe t

Analysis of dispersion If the typ r degree of d pe t ffi tly e ide t up inspec ti it n f q tl be a ta ed by u of mpl g t hn q The e ft b d o unt f d d l n ampl pl t q dr t Dep t f m d m e ually b dem t t d by t k g f q d t d test g th mb f d id l f d th n f their f m ty t th l l ted P di t b t o wh h h been d bed ab Th b rved al ues n be mpared w th th lcul t d by h q r t t f g d f fit d l k f g m t d t f d m d t b t n If the n mbe of quad t c t i g er or f w d d l d f th e w th m y i d d l g t th p t d the p p l t n i l mp d f th l e l th p t d t d y t w rd if rmity i d ted A ther me f d f i e f m nd m s p id d by th a m to wh h i 100 n the a f th Po (d m) d t b t If the tio f ar a et m n l th n 100 gul d per i n di t d if th s g e t th n 100 th d p l mp d

In the case of obviously aggregated populations quadrat data have been tested for their conformity to a number of other dispersion models such as Neyman's contagious Thomas double Poisson and the negative binomial distribution However the results of all procedures based on counts of individuals in quadrats depend upon the size of the quadrat employed Many nonrandom distributions will seem to be random if sampled with very small or very large quadrats but will appear clumped if quadrats of medium size are used Therefore the employment of more than one size of quadrat is recommended

The fact that plot size may influence the results of quadrat analysis has led to the development of a *number of techniques based on plotless sampling* These commonly involve measurement of the distance between a randomly selected individual and its nearest neighbor or between a randomly selected point and the closest individual At least four different procedures have been used (Fig 2) The closest individual method (Fig *2a*) measures the distance from each sampling point to the nearest individual The nearest neighbor method (Fig *2b*) measures the distance from each individual to its nearest neighbor The random pairs method (Fig *2c*) establishes a base line from each sampling point to the nearest individual and erects a 90 exclusion angle to either side of this line The distance from the nearest individual lying outside the exclusion angle to the individual used in the base line is then measured The point centered quarter method (Fig *2d*) measures the distance from each sampling point to the nearest individual in each quadrant

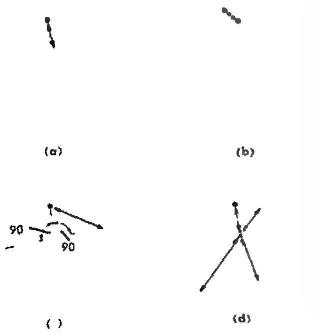


Fig 2 Distances measured in four methods of plotless sampling *(a)* Closest individual *(b)* Nearest neighbor *(c)* Random pairs with 180 exclusion angle *(d)* Point centered quarter x is the sampling point in each case (P Greig Smith Quantitative Plant Ecology Butterworth 1957)

In each of these four methods of plotless sampling a series of measurements is taken which can be used as a basis for evaluating the pattern of dispersion In the case of the closest individual and the nearest neighbor method a population whose members are distributed at random will yield a mean distance value that can be calculated by use of the density distance equation which has been given above In an aggregated distribution the mean observed distance will be less than the one calculated on the assumption of randomness in a uniform distribution it will be greater Thus the ratio r_A / r_E where r_A is the actual mean distance obtained from the measured population and r_E is the mean distance expected under random condi*tions affords a measure of the degree of deviation* from randomness

Additional information about the spatial relations in a population can be secured by extending these procedures to measurement of the distance to the second and successive nearest neighbors or by increasing the number of sectors about any chosen sampling point However since all of these methods assume that the individuals are small enough to be treated mathematically as points they become less accurate when the individuals cover considerable space

Factors affecting dispersion The principal factors that determine patterns of population dispersion include (1) the action of environmental agencies of transport (2) the distribution of soil types and other physical features of the habitat (3) the influence of temporal changes in weather and climate (4) the behavior pattern of the population in regard to reproductive processes and dispersal of the young (5) the intensity *of intra and interspecific* competition and (6) the various social and antisocial forces that may develop among the members of the population Although in certain cases the dispersion pattern may be due to the overriding effects of one factor in general populations are subject to the collective and simultaneous action of numerous distributional forces and the dispersion pattern reflects their combined influence When many small factors act together on the population a more or less random distribution is to be expected whereas the domination of a few major factors tends to produce departure from randomness

Actions of environmental agencies of transport The transporting action of air masses currents of water and many kinds of animals produces both random and nonrandom types of dispersion Airborne seeds spores and minute animals are often scattered in apparently haphazard fashion but aggregation may result if the wind blows steadily from one direction Wave action is frequently the cause of large concentrations of seeds and organisms along the drift line of lakes The habit of fruit eating birds ... the clusters of seedling juniper and cherry found beneath perching sites in trees and ... the occurrence of isolated individuals far from the original source Among plants it seems to be a gen

ral p n ple th t g eg t on is 1 ely r l t d th p ty of the p e f eed d pe al

Ph ll t es of the hab t t Re pon f the nd dual f th pop lation to ariati ns n the abt t al-o te d t g e r e t local con tra t Ea i me ts are r ely un f m thr gh ut o port ge e lly be g m re s t ble f r l fe h n oth th the r lt that p pulat n den ity end t be rrelated d re tly with the fav b lity f th h b t t O ted eact e the po it e r g t e t l ght i te itt m tur g adie t r o so ces f food helter ften br g n mbers of d d l t restricted a ea I the ca es greg t o esult f m spe ie hara t i tic t p n t the e ir m t a d n ed not in l e any soc l e t s t ther member f the popu a n (E VIRO MENT)

I fl e f tempo al cha ges In m t pecie f mmal, da l a d a n l hanges i w ther m ke m m t h ch mod fy e ti g patte ns f d p r M ny f the e e oc ated w th the l b d g of g p a well as with th e f rma n Certa b rd bats d e e butterfl f exampl f rm t n a emblag s t n tim of d and di pe e at anothe Some pe ie t d t be u f rmly d pe d dur ng the s mme b t fl k togethe in i t r H nce temp al ari ti n i the h b t t may often b as effecti e in d term n g di trib t p ttern s p t l a tat

B ha io patte t p d ct n F ctor re l ted t rep od ct h bits like nfl e ce the d pers p ttern f b th pla t and n mal pop l ti s Ma y pl t p od e eget ti ely new n d d l s i i g fr m pa e t o tstock a d p o- d ng d t t l ters ther spr d by mea of rh zomes nd runn d m y ther by ach eve a lo ewh t r d m d t but n Amo g m m l g eg t f r mat g p p se a e m m a e m f ogs and t ads a d the b ed g warms f m ay in ct In cont t, the b eeding t ri tories f v ri fi he a d b rds exhib t m p atı l gula d p r i n

I tensity f comp t tio C mp t t fo l ght ater food and the r s e f th e ir nme t tend t p od e form patt rns f d tr b t n The ath gul p i g f tre s n ma y f est n comm ly att b t d l gely to mpet t n for nl ght, th t of d ert pl t fo l mo t e Thu a if rm d per h lps t r d c th in ten ty f c mp t t wh l ggreg t inc a es t

Social f to s Among m y an m l the m t p f l f e d term ng the d pe i p ttern a soc l ones Th s al h b t l ad t the f rma t n f gr p o oc ties (SOCIAL ANIMALS) Plant ecol g t the t rm ty f r s types f m mm n t es mp d f lt m ny spec b t h th w d a ppl d t m l t is be t fi d t gg g t f d d a l f the m p es wh ch e p te i the life t t e An m l t c l gr p g f m a p t l g b nd h d lon Th y n b l fi d f t n lly s m i g soc t es (wh h t n ar m n g m

polyg mous depend g n the l l t of the p cie) family ciete (e r both parent with their young) f ed g t es (ch a ari fl cks of l ird r sch l of fi hes) and a migra t ry ocietie defen e s ci tie n d othe type Soc lity nfe s ma y ad antages i cl di g g eat eff ency in u ing food n ersati n f b dy l eat d i ing ld w ther m re th ugl e n d t m g of the en i nm nt t incr e t hal ta b l ty i ea ed fa l tati n of mat g impr ed dete ti n f and def e agai t p edat r de ea ed m rtality f the yo g a d a gre ter l fe expectan y a d th p i il ty of d i n of labor and pe lizat n of a t iti D ad antag in clude cre ed mpetit n m e rapid depleti n of re urces greater attra t n f nem es a d mor rap d spr d f par ites a d d ea e D p t th e d ad ntag the de el pm t d per st nc of social gro p i a w de ar ty f nimal pecie ampl e ide ce f it e all urvi l al Some f the ad antage f the ety are l hared l y agg egat n tl t ha e n ocial ba

Optimal population density Th degree of ag greg ti wl ch pr m tes ptimum pop lat o gr wth and urv val h we e rie acc rding to the pec a d the cum tanc Gr ups of or ga ms ft n flo ri h be t if either to f w n r too m ny di d ls are pre e t they ha e n ptim l p p lat n d sty at m i termed ate le el The c dit n of too few ind id al k own as u de cr wd g ma pre ent sufficie t breedi g contact f r no mal rate of ep oduct On the ther h nd o cr wd ng or t high a d sity may es lt i e re mpet ti a d ex es e i terac ti n th t will reduce fe und ty nd lowe the gr wth r te f ind id als The ncept of intermed te ptim l p p l t n d n ty i met me kn wn s Allee a p inc pl [F C E]

B bliog aphy W C. Allee *An m l Agg g t n a St dy n G l So ology* 1931 P Gre g Sm th *Q t t e Pla t Ec logy* 1957

Population dynamics

The ggr gat f pr ces e that d term ne the ze d mpos t o f ny p pulat n In th context popul t s de ed to c st of rgani ms f a gl spe s Th gro p s h r cte i ed by d finit t me t of b rth a d d ath a d oft n by defi te comp iti n w th r spect t the r to b tw e th es a d b twe n the numbe s f d d ls bel g g t d ff r nt age l e An agg eg ti n f nd idu l b ght together fo tuit u ly m y r m y t o st t i a p p l t n th

Population size and density P pulati s e m lly mea u d t ms f numbe f ind d al whil p d t ty is ft xpre d as th n mb f new d id l produ ed pe u t t m The pt h st ds of t mbe p p l t f mm lly l bl fi h In the ta c pod t ty d p p l t re ap- pr t ly me d i t m f m lum th tha mb Th t dv f dyn n su h

In the case of obviously aggregated populations quadrat data have been tested for their conformity to a number of other dispersion models such as Neyman's contagious, Thomas' double Poisson, and the negative binomial distributions. However, the results of all procedures based on counts of individuals in quadrats depend upon the size of the quadrat employed. Many nonrandom distributions will seem to be random if sampled with very small or very large quadrats, but will appear clumped if quadrats of medium size are used. Therefore, the employment of more than one size of quadrat is recommended.

The fact that plot size may influence the results of quadrat analysis has led to the development of a number of techniques based on plotless sampling. These commonly involve measurement of the distance between a randomly selected individual and its nearest neighbor, or between a randomly selected point and the closest individual. At least four different procedures have been used (Fig. 2). The closest individual method (Fig. 2a) measures the distance from each sampling point to the nearest individual. The nearest neighbor method (Fig. 2b) measures the distance from each individual to its nearest neighbor. The random pairs method (Fig. 2c) establishes a base line from each sampling point to the nearest individual and erects a 90° exclusion angle to either side of this line. The distance from the nearest individual lying outside the exclusion angle to the individual used in the base line is then measured. The point centered quarter method (Fig. 2d) measures the distance from each sampling point to the nearest individual in each quadrant.

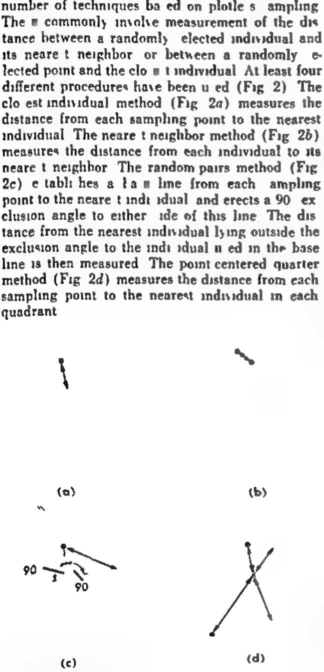


Fig. 2. Distances measured in four methods of plotless sampling. (a) Closest individual. (b) Nearest neighbor. (c) Random pairs with 180° exclusion angle. (d) Point-centered quarter. x is the sampling point in each case. (P. Greig-Smith, *Quantitative Plant Ecology*, Butterworths, 1957.)

In each of these four methods of plotless sampling a series of measurements is taken which can be used as a basis for evaluating the pattern of dispersion. In the case of the closest individual and the nearest neighbor methods, a population whose members are distributed at random will yield a mean distance value that can be calculated by use of the density-distance equation which has been given above. In an aggregated distribution the mean observed distance will be less than the one calculated on the assumption of randomness; in a uniform distribution it will be greater. Thus the ratio r_A/r_E, where r_A is the actual mean distance obtained from the measured population and r_E is the mean distance expected under random condition, affords a measure of the degree of deviation from randomness.

Additional information about the spatial relations in a population can be secured by extending these procedures to measurement of the distance to the second and successive nearest neighbors or by increasing the number of sectors about any chosen sampling point. However, since all of these methods assume that the individuals are small enough to be treated mathematically as points, they become less accurate when the individuals cover considerable space.

Factors affecting dispersion The principal factors that determine patterns of population dispersion include (1) the action of environmental agencies of transport, (2) the distribution of soil types and other physical features of the habitat, (3) the influence of temporal changes in weather and climate, (4) the behavior pattern of the population in regard to reproductive processes and dispersal of the young, (5) the intensity of intra- and interspecific competition, and (6) the various social and antisocial forces that may develop among the members of the population. Although in certain cases the dispersion pattern may be due to the overriding effects of one factor, in general populations are subject to the collective and simultaneous action of numerous distributional forces, and the dispersion pattern reflects their combined influence. When many small factors act together on the population, a more or less random distribution is to be expected, whereas the domination of a few major factors tends to produce departure from randomness.

Actions of environmental agencies of transport. The transporting action of air masses, currents of water, and many kinds of animals produces both random and nonrandom types of dispersion. Air-borne seeds, spores, and minute animals are often scattered in apparently haphazard fashion, but aggregation may result if the wind holds steadily from one direction. Wave action is frequently the cause of large concentrations of seeds and organisms along the drift line of lake shores. The habit of fruit-eating birds gives rise to the clusters of seedling junipers and cherries found beneath such perching sites as trees and fencerows, as well as to the occurrence of isolated individuals far from the original source. Among plants it seems to be a gen-

eral prin ple th t agg gation s i er ely related t th p c ty of the p for eed d per al

W n lf t s l th h b tat Re p e of the ind d al l the p p lat on to va iat on in the habitat al t d to gi e ri e t l cal co e tra t n En onme re rely u f rm thr ugh t som port s g lly be m re u tal l f l f tha th r ith the re lt that p pulati d ty t nd t be correl ted d ectly w th the fa rab lity f the h b t t O e t d re cti ther p iti e or neg t e t l ght t n t e mo t re grad ent to so ces f food o helte oft b g n mbers f ind d ls t a re t ted rea In the e ca g g t res lts f om pe chara teri t c respo t the en ment a d n ed n t i l e any soc l i to ther members f the popu lati (e ENVIRO MENT)

I fl ence of t mp l h ges I m st pec f n al, d ly d a n l hange in weath r er k mo m t wh h modify e ting patte f disp rs o M y of the e e a ted w th the dib d g f gro p a well as w th th r forma tion. Cert n b d b t nd even b tterfl es f r ple f rm roo t embl g s at e t me f d a d d pe t another Som sp cies t nd t be uf rml d pe ed d ring the summe but fl k t g th i w ter H e t mp al a i t n in the h b t t m ften b as effecti in det mini g dis trib u n p tt rns s p tial ariatio

B ha p it in r p d ti n Fact s re lated t r pr d t ve h b t l kewi flue ce th e d pe s n patter of b th pl t a d mal p pu la Many pla ts rep oduce egetati ely w i d d l i g f om p ent rootst ks and pro d g d u ct cl te s othe p d by me n f rhiz s d ru ne and m y thereby ach e a wh t m ra d m d st bution Amo g ani l g g t n f m t g purp e a c m m n m f og and t ds d the breeding swarms *f many* s t In ontr the b ed ng te t nes f fi hes and bird e hib t a c m p t ly regula d p

I tensi y of comp t t n Comp t t f light, er food d the r so s f th e nment tend to prod n nif m pattern f d t b tion Th th reg l p ci g of t ee ma y f rests is comm nly tt b ted l gely t e mp t t n for l ght, th t of de ert pl nt f r oil m sture Th s f rm d p s h lp t educe the in ten ty f c mp t ti wh le gg g t on i reases n

S ial f t s Am g m ny nim ls th m st po rf l f s determ g the d spe n p tt rn t soc l The s cial hab t l d t the fo ma t f gr p c ti (SOCIAL ANI IALS) Pl t ec l g ts e the term s c ety f ar ous types f m o mm t e mp d f ev al t m spec es b t wh n th w rd ppl ed t an m ls t best c fi ed t agg g t ns f d d al f th s m sp c wh h p te ther lif art t es A m l t tes l g p ang in ze l m p r t l g b d h d colon es Th y be l fied f et lly g soc t es (wh h m t e mo g m u p lyg mous depend ng on the hal t f tl e pe cie) fam ly i tie (ne r boil pa ent with their young) fee l ng ci tie (h a ari fl ck of bird hool f fi l e) and a migra tory cietie defen e sce etie and other types Sociality e nfe many ad ant ge includ g great eff n y in ecur g food rvat n f l dy l eat d ri g c ld we the m re th ugh e n dit o ing f tl e en r nment t in rea e it hal it l ility i rea ed facil tati n of m ting impr ed d tect of and def n e ga n t p edat de rea d m rtal ty f the y ung and gre ter l fe e pe tan y a d th p l lity of d i n f lal r and p al zation f a t it es Di dvantage i cl de i crea ed mp titi n mo rapid deplet of res u ce great att acti n f en mi and m re r p d sp ead f pa a ite and d De pite the e di d ant ges the de l pm t and per i t e f social gr up in a wid ariety f anim l spec is ample e ide ce f its all s rvi al al e S me f the d ant g s f the c ety are al sh red l y aggregat th t have n social ba

Optimal population density Th degree of ag g g t on wl i h pr m te pt mum p pulation growth nd rvi l howev r var e according to th peci and th e m ta Group f r gan m ften fl u h b t f either t o f w nor too ma y ind idu l are p ent th y have an ptimal p lation d ity t ome i termed ate level The dit of too few di id l known as u de c wding may p e ent ff ient b edi g tacts for orm l rate f rep d tio On the other hand er wd ng r t o h gh d s ty may e lt i ere mpetit n and exce e nterac tion that w ll redu fecund ty and lower the growth rate of ndi d als The concept f an i term d ate ptimal popul t den ty i somet mes known as Allee s p ciple [F C E]

B bliog phy W C. Allee *A im l Agg ega tio a St dy n G n al S l gy* 1931 Gre g Smith *Qua t t ti Plant Ecol gy* 1957

Population dynamics

The ggregat f pr that determ e the si a d c mpo it n f a y p pulat In th conte t a pop l ti s de d t t f rga ms of a s gl sp c The g p ch racte i ed by defi t t me f birth and death d oft by a defi ite mp ti n with respect t the t betw n the and betwee the numb of ind dual b l ging t different cla A ggr gat f i d du ls bro ght t geth fo t t sly may or m y n t con tit te pop l ti th e

Population size and density P pul t n s e s rmally me s d n t m f mb of d d al wh le pr duct ity i oft xp es ed a the mb r f ew d du l p od d per n t t me Th re ex pt h a ta d f t mb r p p l t f mmer lly l ble fi h l th n t e p d t ty d p p l t n a ap p p ately m d t m of m l me th th n umb Th t d f d) m

population merely requires consideration of individual growth rates in addition to numbers and ages, and we will here limit our discussion to populations measured by enumeration.

In practice, it is difficult to define the limits of a population, and enumeration normally measures some type of population density. Crude density is the number of individuals per unit of selected space or volume. Examples of this are the number of deer in a county or other areal unit, or the mean number of fish per acre of water surface or per cubic meter of water. This measure suffers from the fact that the units of area and volume are heterogeneous and the population does not utilize all of the available space. Ecological or economic density refers to the mean number of individuals per unit of space actually utilized. Sometimes it is easiest to enumerate a population under conditions of maximum density, as when fur seals or colonial birds are on their breeding grounds, when deer are in winter yards, or when snakes are congregated in dens. Often the only practicable measures of natural populations involve relative density and are designed to show whether a population is increasing or decreasing without determining its actual size. Thus the number of birds seen per man-hour of walking and the number of squirrels treed per dog-hour have been used to compare population densities in different years and places. Formidable statistical and practical problems are involved in the mensuration of natural populations.

Population growth. A population can gain in numbers only by birth and immigration and can decrease only by death and emigration. In considering theoretical population dynamics, we customarily ignore migratory movements and concentrate our attention on the birth and death processes. Individuals of every species have the potentiality for producing more offspring than are required to replace the parents. Without this potential the species could not meet emergencies and would necessarily become extinct. Some organisms reproduce once per lifetime, others many times. Some produce tremendous numbers of gametes, others few. Also the age at which reproductive maturity occurs varies tremendously—from a few minutes in bacteria to more than a century in the giant *Sequoia* tree. These life history features determine the potential growth rate of the population or the biotic potential of the species.

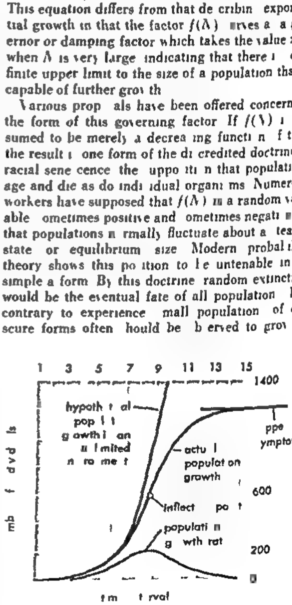
If these life history features remained the same in successive generations, the population would ultimately grow in accordance with the equation $N = Ae^{rt}$, for which the growth rate at time t is $dN/dt = rN$. In this formula N is the population size at time t, A is a constant, e is the base of the natural logarithmic system, and r is a measure of population growth. The value of r which is determined by natural history features is commonly referred to as the intrinsic rate of natural increase, and it has been proposed to define biotic potential as the normal maximum value of r for a given population.

This exponential form of potential population growth implies exceedingly rapid expansion. A single individual of an annual plant in which each individual produces only two viable seeds would leave 1,000,000 descendants in 20 years if all seeds survived, and in fact every species is theoretically capable of overflowing the earth. In actuality, shifts in natality (birth rates) and mortality inhibit unlimited exponential growth.

Population control or regulation. Since potential population growth is exponential while real population size is limited, much interest and controversy has centered about the form of actual population growth. Commonly, when the size of a growing population is plotted against time, the result is a broad S-shaped (sigmoid) form of growth curve which often appears to be symmetrical about a central point of inflection, where the rate of growth shifts from increase to decrease.

Attempts to give a generalized mathematical formulation of population growth have led to consideration of equations of the form $dN/dt = rNf(N)$. This equation differs from that describing exponential growth in that the factor $f(N)$ serves as a governor or damping factor which takes the value zero when N is very large, indicating that there is some finite upper limit to the size of a population that is capable of further growth.

Various proposals have been offered concerning the form of this governing factor. If $f(N)$ is assumed to be merely a decreasing function of time, the result is one form of the discredited doctrine of racial senescence, the supposition that populations age and die as do individual organisms. Numerous workers have supposed that $f(N)$ is a random variable, sometimes positive and sometimes negative, so that populations normally fluctuate about a steady-state or equilibrium size. Modern probability theory shows this position to be untenable in so simple a form. By this doctrine random extinction would be the eventual fate of all populations, but contrary to experience, small populations of obscure forms often should be observed to grow to



Population dynamics. Three types of growth curve using the same data.

tr me d us size at least app oaching the condit on for fi g th e rth

In a some hat m re real tic app oacl tl e go erning f t egarded as a decrea ing f ction f popul io d ty that the pop l t on i hib t gr th bey nd a tain e It s ol v h were that m imum p pilat n ize mu t al be affected by th qual ty of the h bitat Pop la t n f th am pe ies a e c mm ly m re d e er o than i th s owing t diffe en m th r l bil ty of es nt l es rces el a f d and n t g te Theref it is u al t p ak f a ca rying apacity f r a y gi n l bitat ndi d fi e th a the m xim m teady tate p p- l t of a g e spe es that can l e pp rted th re

C ry g cap city N g ne al g eement ha bee a hed on a pr i defi it n f ca ry g p cty b t it eems sential to recognize that th hypothet l upper l m t may met m s be e eeded tempo a ly F r e mpl popul ti n as d nse a 17 ind d l per quare yard h e been ob ed hou m ce d the horde f l c t th n h b g l mm n s a d th a m l that o r m b eak f e c ed th apa ity of the oc up ed l d t p de f od a d helter

E m t l t In pr ct c t d nts f n tur l pop l t ft n th k f p p l t n d n ty t in ab l te t rms but a a den ity r la t e t some dard h a the max m m th t could be pported Th *the fa t f(N)* g ing pop l t n gr wth i m t eal t cally egarded a a funct n f the *fulfilled* p ib l t e f th. Th term e onme t l res t c ha bee e pl d t e *pre thi* ame n pt that r es t t fu th *growth* r s as th m t app h at rat

l k n f m ob *rvati ns* th fi ld d f om l bo at y xper m nt th t c owd ng d e p ed death at s a d nh b t p o- d tion P th ge c g isms c spre d rap dly th gh p p l ti wher ther is el c t t bet e d du t m tab l e wa t s m y a m l f t t l el malnut t n r th d fi ond t n ma ak n th di d l nd in erve wded pop lat n ther may be t te f en e a h f d nd m t g Al var o symp r d g There th f e d f r m l ing nd finall h h t g p p l t gr th th t t y th gr w g p p lat o h ts n g t e f db k. The r ti lly l y ue f m tal y or t il ty th t alw ys d p dent of popul t n si o d ty n th m th t al e c ld n t p nt g wi g p pul n ns f m or a nally fl w g the th *D y l t s N* m u st d t l tr d t pend t f ct wh h re the r t lly ap bl fact l eg l t ng pop l t n and d ty d pe de t control h h ca n e t rni g ff t Mu h h urr u d d th *pt od th*

arying d finition given to the ari u cla se of factor Tl us it h l een cla med tl t a len ity d pe dent f ct r mu t l e wh t thers l a e called d n ity re p n i e tl at i tl e inten ty f the fa t m t be altered l y cl angi g p pulati n den ty S nce p p l ti n den ty ca not ord narily l e on id red t alter we ther r cl mate it ha been e t ded that meteor l g al c nd ti ns are den ty independent and nnot reg l te p pulat n ze Other ha e rec g i ed that weatl er d me times perate in a d n ity depende t manner or they ha e maint ned that tl e tr ie den ity depend e t reg ilat ng f ct r in uch ca e mpetiti n f helter l etween the i d idual wh ch force the l e t l e xp ed t unfa al l weather c nditi Anoth pr min nt l ool f tl ght i itterly pp ed t thi gene l apjr ch nd m i ta n that pop ilati n eld m attain a le el wl ere de ity eff t a imp rtant l ut re normally l eld at l we le el by e iro ment l nadeq iacie and m rt lity fa t rs ich a extreme f weatl er

Und p pul t n eff ct At th other end f tl e cale of iz tl e is al a gr t d l l e d nce in m ny spec e f r nde p pulat n effect p p ul ti n gr wtl In pa e p pulation f males may ha e d ffic lty find mat A mall p pulat la k tl e daptab lity t ha ged d t on that i pro ided by a large t ck of g netic rial il ty a d th d f ct m y be ggra ated by i l re ding Al popi lat n ften c nd ti n ther sur o di gs nd m dify th impa t f n ir nmental f ct r The fo e t l t ally p ote t the tree fr m wind d m g e e e n lat and e ap t n Th ad a tage f mainta i g th p p l ti n l e ome m imum l vel are of i i g eg i us n mals su h s b d fl ks a d herd of i ng lat a d e n m the al n t wl e ant be s nd term te f xample exerci c n d rable ontr l the limat n d th l ial tr e ti In additi n ma y a es a e kn wn where often f b cur e p pul t n em un ble t e st t n t f th umb s fall bel w me m n mum level

Fr m th e b rv t n it f llows th t any g n r l ed ept f th gr wth g v rno *f(N)* m st pr ide f th f ct t be mall i v ry m ll populat n t to m x mum at m pt m m pop l t n z d t d h e to bef r th pop l t n fl ws th earth In the word the grow g popul t m y e l ib t p s t feedb k p t ta n si e rang d n i l edb ck t h gher l el T date h w v r ve y l ttle u h s b mad f h ghly g n l ed g e n g f t

A tual p pul t n g wth Th l t c f n t n h n en th equ t o most mploy d for r p e nt g tu l p pul t gr wth Th equatio i it d ff rent l f rm

$$\frac{dN}{dt} = rN\left(1 - \frac{N}{K}\right)$$

whe e K ep e t th pper ymptote o m mum att i ble by th p pul ti n n q e t n He the t n ty f th go e n ng fa t r de e

linearly with population size so no account is taken of underpopulation effects The integrated logistic curve however is sigmoid shaped and symmetrical about its central point of inflection It often gives a very good representation of the course of population growth It occupies a prominent though controversial position in modern theories of population dynamics

Optimum yield An important consequence of the sigmoid form of population growth is the fact that populations of intermediate size are capable of more rapid growth and greater productivity than are either very large or very small populations If growth were strictly logistic the most rapid growth would occur at a population size of $K/2$ and the growth rate at this point would be $rK/4$

When man begins to exploit a large population as in commercial fishing the effects of his catch will be to reduce population size If exploitation is not too intense the smaller population will lie on a steeper portion of the sigmoid growth curve and will therefore be more productive than the larger population The population is said to compensate for the increased mortality In theory productivity will increase with rate of exploitation to the point where population size reaches the inflection in the growth curve Hence the maximum possible sustained harvest would be obtained by reducing the population to the inflection point and harvesting at a rate just sufficient to maintain this size There are many practical difficulties in all actual attempts to determine the optimum rate of harvest and the general problem has become widely known as the optimum yield problem It is noteworthy that if the population is overfished so that its size passes below the inflection point productivity will decline with each further decrease in size Then each increase in the effort to harvest a crop will have the effect of reducing the long term yield There is reason to believe that many commercial fisheries are reducing their total catch by fishing too intensively

The same principles apply to attempts to control noxious species Rodent populations for example compensate for mortality and it is possible to harvest a large annual crop of rats without actually reducing the population Programs of killing are often discontinued before the population passes below the inflection point where control would become progressively easier Consequently the most effective way of dealing with noxious forms is often to reduce the carrying capacity of the environment programs for improving garbage disposal and for ratproofing buildings will often be much more effective than programs of killing

Fluctuations Populations of many species fluctuate in size from year to year and a very large literature exists on this subject Plagues of rodents and locusts are recorded in the Old Testament and similarly ancient sources and the migrations of the lemmings and the eruptions outbreaks or gradations of various insect populations have often attracted popular attention There is a tendency for eruptions to be most conspicuous in high latitudes and other regions where the biota is composed of relatively few species of plants and animals Outbreak years typically follow periods of buildup during which the population nearly realizes its potential of exponential growth Eventually population size exceeds the capacity of the environment to sustain it and the population "crashes" often dropping abruptly to a very low level

Cycles The most discussed of the fluctuating populations have been those of certain gallinaceous birds rodents rabbits and fur bearing mammals of northern regions The records of the Hudson's Bay Company for example provide figures for a long series of annual catches and many students of populations have considered that the rhythms or cycles in such records indicate a regular periodicity in the rise and fall of population size Although cycles of various length have been postulated most competent opinion in recent years has considered that there are two predominant cycle lengths a short cycle of approximately 3 or 4 years and a longer cycle often referred to as the 10-year cycle

Numerous explanations have been advanced One of the most popular has been the belief that the populations follow some extraterrestrial rhythm especially the sun spot cycle Such hypotheses suffer from numerous observations indicating that populations in different regions may be out of phase with each other Others have based explanations on population dynamics claiming in effect that the cyclic species are deficient in feedback mechanisms so that exponential growth is not inhibited until disastrously high densities are attained Still others have attributed the cycles to interactions between two species herbivores and their food plants or predators and their prey The predator is visualized as growing until it exhausts its food supply and then undergoing violent decline until the prey population has time to recover These hypotheses are not entirely satisfying because it is difficult to see why many species with diverse life histories should adhere to two basic cycle lengths The Canadian lynx and the chinch bug for example are both considered to exhibit 10-year cycles

Other factors It has also been noted that random variables such as the sizes of the numbers turning up on a roulette wheel will when plotted on graph paper give an appearance of regularity and show a series of peaks occurring at a mean interval of 3–4 numbers It has been postulated that the great variety of haphazard factors affecting population size constitute a causal system comparable in complexity to that governing the roulette wheel and that the appearance of peak population years may therefore be considered to be governed by a random variable

Whatever may be the causes of population fluctuations they are often of great practical importance Much remains to be learned about possibilities for predicting peak years in crop damage and

m th harrest f food game a d f bearing an m ls, f m n mizi g the e pectat o of financial lo res lt g from these fl tuat ons

Age structure N t only the but al o the compo ti n f a p p lat n i verned l y tl e ag schedules f n t l ty a d m tality If the life h tory fe t es and th death rate f r ndi d al f h a e em const t a popul tion will e en tuall atta n a t bl e d trib ıt s icl th t tle nd dual of an p rt lar ag co titute a fixed p portı n f th t tal In h man p p lati n bo t e-half of the i d duals typically fall m th ge range f 15–50 ye rs but th rat of ld ind d al t ry y g diffe greatly from t m ther Con eque tly di ea of ld att great t import e in p pulat s here lif e p t cy i gre te t P l lem lat g to t uct r al of great ignific e h ma pop l t It i pp rent th t a pred to c n b efit ma by ele t ely kill g su pera ted g m an m l thus e g pr d tivity that u h predator can work gain t n ff rts t e t l pec es even while kill g m ny f the de able forms *See* ECOLOGY [L.C CO]

Bibl phy P p lat o stud es anim l ec l gra d d m g phy *Cold Spring Ha bor Sympos Q t B l* ol 22, 1957

Population genetics

The t d f b th ype me t l and tl r t c l c n equen es f Me del n he ed ty in the p pula h lev l t d t t t l cal ge tic h h d l w th the ff p f pec fied parents th f m l al lev l The g etics of p p l t st des th f qu nc s of gene g otyp and phen typ a d the m tin y tem It ls t d th f th t m y alter th ge ti comp sition t a pop l t n t me u h ec t m tat on m grati d term t betw gro p e lect n lt n f m g typ c d ff ent l fert l i a d the d m h nges nc ed by th m t p oc ep d t n f m ge e t n t gene t n Th typ f t dy abl e t ga n d tand of the elem nt rı t p h f gı lev l t n Th p c ples f p p l t n ge eti m be ppl ed t pla t d the a mal well a m n. *S* EVOLUTIO AN ME DE I t

Mendelian population A Me d l p p lat s a gr p l d d al wh i t b e d m ng th m mle d g t e t n y tem f mat g a d f m m e o l b eed mm ts b them l Th se d d l h mm ge p l h h the t tal gen t nt f th g o p A Mend l a pop l t n the u t f t dy n pop t ng t The p p l t m b l g ay m ll d t b d t g h d f m pe ws r t h h m t f me w l ted t p t ll l t d M nd l p p la t M d l p p lat a g n t r th th t l rm Me d l a p p latı d ffe from a h th th t g t o h mo mal rgani tion not n e arıly in tl eir taxonomic f atu e The term deme igin lly defined a an eml lage f ta on m cally l ely relat d i di id al l a l e n ied as a y nym f r Me deli n population Cam deme a deme fo ming m re r le i lat d l cal intral eeding c mm i nity would l e a l etter ub t t te

Mutation pressure Ce e mutation ari from t me t t m in n t re The cau f mutation are t fi lly kn wn a d th t can be said tl at mutation ari e spontane ly The effect of a new mi t nt gene i unp d tal le and the gen i therefore id to mut at r ndom" O prop erty of mutat on ha been tablished t is recur rent E h type of gene m tate at certain t pe g erat The rate i u ually low—al out 1 m tant in 10 –10 g e of a g en rt rying fr m l to l c n the ch m me even u de form c d tions I zing radiat on erta chemical h at and m ther ag nt rea the rate f mı tati n *Se* MUTATION

L t μ be th rate f m tation from an all l A t an th r f m a pe g eratio If a f ct o p f th g e f a p p lation i A i n generati the in the n t gene t the freq ıency of A will be d m hed by th m unt $p\mu$ th t tl e n w f equency f A will be $p(1-\mu)$ The amo nt of ch ng $p\mu$ is sa d t b d ie to the mutati n pre re If th p e ure i n pp d ge e at aft ge eration th ge e A will gradually di app ar f m th pop l ti n $p = p(1-\mu) = p$ whe p th itial gene f q cy d p is the f eq e y afte g e ati n Th ref f all e t g ge e the e m t b me k d of c m pen t g m h m which si pports it co ll g p e c inn t O mpo ta t g bl m in p p l t ge eti i tl m l n m f ma nte ce f a i a pop ılat r of its ch ng i fre que f m g ti to gene at n

If dd t t the m tatio f m A to there is e e e m t t f m t A t the r te p ge erat n th n the net m t of ch nge in the fre e y of a $\Delta q = p_l - q$ At th t me wh the pp si cha g el h the th w ll b ch ge in g f eq e y d y t th rrent mutatio s Th tate f ff a d t be in equil b m d s btai d when $\Delta q = 0$ th t $p = /(\mu +)$ d $q = \mu/(\mu +)$ wh q f q y f q th q libr m p t f r a and p i th eq l brium poi t f r A Th eq l b m g freq n e a d t rm ed b th pp te f m tat n o l a d r d p d t f th nt l f eq es f the gen the p pul ti n The m nt f h ng n g e f que y per g ati n I ge whe the rr nt q f w y f m the eq l b m g th wh n q l t q S b t t t g $\Delta q = -(\mu +)$ $(q - q)$ i d ting th t the am nt f ch p r gene t n i pr p rt l t th devi t n $(q - q)$ It al h w that f $q > q$ q de s d f $q < q$ q i c th t q w ll pp a h q f m th d S h a eq l b i m i a d t

be stable. The changes in q described above are independent of the mating system practiced in the population.

In nature and under artificial conditions the mutation rates may not remain constant in all generations but may fluctuate within a certain range from time to time. In such cases, instead of a single fixed equilibrium point q, there will be an equilibrium distribution of q within a certain range, and the apparent change in gene frequency from one generation to the next may be purely a stochastic phenomenon without necessary long-term significance. The same remark applies to all equilibria to be established in subsequent paragraphs. *See* STOCHASTIC PROCESS.

Migration and intermixture. If a fraction m of a population with a gene frequency q consists of immigrants from outside and the immigrant group has a gene frequency $\bar{q}$, then the new gene frequency of the population will be $q_1 = (1-m)q + m\bar{q} = q - m(q - \bar{q})$. The amount of change in gene frequency in one generation is thus $\Delta q = q_1 - q = -m(q - \bar{q})$, showing that the change is proportional to the deviation $(q - \bar{q})$. This expression for Δq is of the same form as that for mutation. If the immigrants have the same gene frequency as that in the population, there will be no change in gene frequency in spite of the migrations. The continued intermixture of neighboring populations will eventually make them homogeneous in terms of gene frequencies. Thus, if a large population is divided into a number of partially isolated subpopulations, migrations between the groups will eventually make all subpopulations have the same gene frequency $\bar{q}$, which then denotes the average for the entire population in the absence of other disturbing factors. If the local populations are differentiated genetically, there must be some mechanism (for example, local selection) to counteract the pooling effect of migrations so that an equilibrium condition may be reached. The change in gene frequency due to migration is independent of the mating system practiced in the population.

Mating systems. In a gene pool with respect to one locus, if a proportion p of the genes is A and a proportion q of the genes is a, the genotypic proportions in the population are still unknown until the mating pattern is specified. The mating pattern is a system by which the genes are associated into pairs to form the diploid genotypes. The mating systems vary widely in nature for different organisms and populations. Thus wheat may have 1% cross pollination and 99% self-fertilization, whereas maize practices just the reverse. One of the simplest and most extensively studied systems is random mating, also known as panmixis.

Panmixis. Random mating between individuals is equivalent to a random union of gametes. Thus if the $(pA + qa)$ gametes of one sex unite at random with the $(pA + qa)$ gametes of the opposite sex, the resulting genotypic array will be $p^2 AA + 2pqAa + q^2 aa$. These genotypic proportions will be realized only in very large populations. *See* HARDY-WEINBERG FORMULA; HUMAN GENETICS.

Inbreeding. Inbreeding refers to mating between genetically related individuals; the frequency with which two A gametes unite will be greater than p^2, and a similar situation is true for gene a. Consequently, inbreeding leads to an increase of homozygosis at the expense of heterozygosis. Let H be the heterozygosis proportion in a population, H' that in the preceding generation, H'' that two generations ago, and so on. On continued systematic inbreeding, the manner in which the value of H decreases is shown in Table 1.

Continued close inbreeding such as those degrees indicated in Table 1 and many others eventually leads to complete homozygosis. The population will then consist of pAA and qaa; that is, an A gamete will always unite with another A gamete and an a gamete with another a. Inbreeding between remote relatives does not necessarily lead to complete homozygosis but only decreases the heterozygosis below the random mating level to a certain extent.

The inbreeding coefficient is an index intended to measure the amount or degree of inbreeding that has been accomplished in a population. Various indices may be constructed. One that has been proved highly useful in both theoretical investigation and practical breeding work is the inbreeding coefficient F, defined as the correlation coefficient between the uniting gametes. The value of F ranges from 0 for random mating to 1 for inbreeding in a homozygous population, as shown in Table 2.

In an inbred population where the correlation between the uniting gametes is F, the genotypic array in the population will be

$$
\begin{aligned}
AA:&\ p^2 + Fpq = (1-F)p^2 + Fp\\
Aa:&\ 2pq - 2Fpq = 2(1-F)pq\\
aa:&\ q^2 + Fpq = (1-F)q^2 + Fq
\end{aligned}
$$

The last set of expressions shows that the population may be mathematically considered as having two separate components: $(1-F)$ panmictic and F fixed. If the mating system is such that F remains constant (instead of increasing) from generation to generation, the population will reach an equilibrium state with the genotypic array shown above.

Table 1. Decrease in heterozygosis with systematic inbreeding

Inbreeding system	Manner of heterozygosis (H) decrease	Limiting ratio
Self-fertilization	$H = \frac{1}{2}H'$	$H = 0.500H'$
Simple backcross × recurrent parent	$H = \frac{1}{2}H'$	$H = 0.500H'$
Brother × sister	$H = \frac{1}{2}H' + \frac{1}{4}H''$	$H = 0.809H'$
Younger parent × offspring	$H = \frac{1}{2}H' + \frac{1}{4}H''$	$H = 0.809H'$
Half brother × half sister	$H = \frac{3}{4}H' + \frac{1}{8}H''$	$H = 0.890H'$
Half brother × full sister	$H = \frac{1}{2}H' + \frac{1}{8}H'' + \frac{1}{8}H'''$	$H = 0.8[illegible]0H'$
Double first cousins	$H = \frac{1}{2}H' + \frac{1}{4}H'' + \frac{1}{8}H'''$	$H = 0.9[illegible]0H'$

al 2 R ge l al of F th l b ed g oeffel t

R d m m t g

	A		
A	p	pq	p
	pq	q	q
	p	q	1

Correl t $= 0$

I b ed pop lat o

	A		
A	$p + Fpq$	$pq - Fpq$	p
	$pq - Fpq$	$q + Fpq$	q
	p	q	1

Co l t $= F$

I b eed g h m zyg pop l t on

	A		
A	p	0	p
	0	q	q
	p	q	1

Correl ti $= 1$

The corr l t n between u t ng gam tes d the lat b t een m t g nd d al I a r lib m p pul t if M de otes th el n bet en mates, th n $M = 2F\ (1 + F)$ $M/(2 - M)$

Genotypic selective values W th la ge p p l u n t ll t d d I prod e the same um er of ff pring In the tuat n to be c n ider d h a ge numbe of l ff pr g b t h f the g types in the p pul t a e t d ed hil gn the r nd m fl tu t i the um of ff pri g f om f m ly to f m ly Fu th n e, t a m d th t the p p lati n s larg hat nly th rel t e f eq i of the i u n t es and g the p p l ti are f n et. S ppo th t th erag umber f ff pri g for h g typ i s f ll w AA 2 00 A 2 50 a 1 50 G the d ff e t l rate of rep od tion the ew g e f qu cy of th n xt gener t n m y b l ul t d l a m h t i nly th e l ti e m g t d th t matt r th e e p od ti tes m y b s mpl fied to th t W W W_{22} = 1 1 2 0 75 o alt t ly t 0.80 1 0 0 1 d r to t d rd th d s ipt n u i ent t t ke ne f th th pr d tive al es un ty I the p i us e mpl de pend g upo heth the pr d ct l f 1 0 o 1 t ken n ty (th d d) th t f al 1 0 r 0 60 = 1 − 0 25 r 1 − 0 40 = 1 − s n gen) The l e f k ow a th el t n coeffi ient g t th g otyp Wh n el c tion coeffi ent ed i h uld lways b t t d t h g type h s b en employed s the t d d hat $l\ s\ l\ t$ Th doct i e f th rs l f th fittest n ed l fi t n f m th g n t w

p r t Th relati e gen typ c rep odu ti lues (W W W f the p eced ng p agr ph) imply g e a ex p t f cto d cr pti n l y which the g etic compo ti f the ff pri g ge erati n may be related t that f th pa ent generati n Th e W alu in l de all a r e f r differe tial rep r du t n ch f nd ty fert lity e l m tur ty and pa ity rv al a d viabil ty le gth f re p od ti e l fe a d m ny th er d pend n the d tails of the life cycle of th rg ni m The W al e met me l iefly ref rred to rel ti f t ne n t ne arily corr lated with any l serv al le m rpl l gi l h ra ter t c matt r l w d i al le the m y e m t man Fr m th g net ewp nt o ly th who rep od ce u t Th i nat al lect n h n pa ticular purp e ex ept t perpetu te th e wh re ft t rep d ice under the gi en co d t O ly whe a ha act ri tic l w the o g n ms rep od cti e pacity d t ha e a genet c effect n the ul q ent g ner ti ns

S l n p t e and q l bri m Th effect of l cti n m y l e de r bed n t ms f ch nge i ge frequency In random m ti g p pul ti n w th r pect t ge e l u th s tu ti i a h wn in Table 3

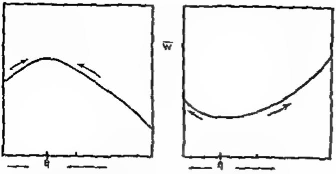
The pop lati n fter sel cti n i th p rental p p lati f the t g er ti th o gh rand m m t g The l ie $\overline{W}$ i the t tal f the el ted pa ent l populati b t m y l b r gard d a th a rag $\overline{W}$ e of the rig n l ele ted pop la t on Th new frequency of gene a m the e lected $q = (pqW + qW)/\overline{W}$ a d there f e the mou t f cha g p ge er tio is $\Delta q = q - q$ or m e pli tly

$$\Delta q = \frac{pq}{2\overline{W}} \quad \frac{d\overline{W}}{dq}$$

Th p sent the ffe t of le tion pr ure n ge e f eq Wh n p q i ero the e is n h n e n g ne f eq e y th r n h l c t th b e f lt rn t e Th r f ll lect n ff t l the fa t pq F rth when p q i ry m ll th l t n i i effec t e whether t f r t a g ne Be de the e term n l d t f the t a q lu h th t $\Delta q = 0$ t ll d the q il b i m al e f ge f q y be p p l t w th th t p rt ul r g fr qu n y will r m n h n ed p te f the l ti n pre ur Wh n h a q

T bl 3 **Effect f s lect l d m m ti g pop l t on**

typ	F eq cy f	F t es W	F eq cy ft lect fW
AA		W	pW
A	pq	W	pqW
	q	W	qW_{22}
T t l	1 00		$\overline{W}$



( ) (b)

Fig 1 Diagram of the relationsh p between the ave age fitness value $\overline{W}$ and q the equil brium point for a (a) Stable equ librium (b) Unstable equil b ium

value exist it must be the following solution of the equation $d\overline{W}/dq = 0$

$$q = \frac{W_{11} - W_{12}}{(W_{11} - W_{12}) + (W_{22} - W_{12})}$$

In order that q be a positive fraction the differences $W_{11} - W_{12}$ and $W_{22} - W_{12}$ must be both positive or both negative that is the selective value of the heterozygote mu t be lower or higher than those of both homozygotes For all other cases there will be no equilibrium except when $q = 0$ or 1

Stability of an equilibrium The value of $\overline{W} = p^2W_{11} + 2pqW_{12} + q^2W_{22}$ may be plotted against the value of q or p When W_{12} is greater than W_{11} and W_{22} the $\overline{W}$ curve has a maximum point (Fig 1) The q value corre ponding to the maximum value of $\overline{W}$ is the stable equilibrium point This means that whether it i maller or larger than $\hat{q}$ the q value will approach $\hat{q}$ as el ction proceeds from generation to generation A stable equilib rium of this type leads to balanced genetic poly morphi m that is to the coexistence of alleles in a population Conversely if W_{12} is lower than both W_{11} and W_{22} the $\overline{W}$ curve has a minimum point yielding an unstable equilibrium the selection pressure will make the q value move away from the equilibrium value toward either 0 or 1 depending upon which side of the equilibrium the q happens to be Con equently selection against the heterozygote leads to the elimination of one of the alleles In more complicated situations there could be more than one stable or unstable equilibrium value in a population or both

The genotypic selecti n values W_{11} W_{12} W_{22} have b en as umed to be fixed for each genotype but in nature they may vary in arious ways In addition to the omnipres nt random fluctuations the elective values may vary with the gene frequency itself For instance a gen type may be favored by selection when it is rare in the population but suffer a disadvantage when it is too common For such cases there will be an equilibrium yielding genetic polymorphism Let U_{11} a function of q be the varying selective value of genotype AA and so on Then the equilibrium alue of gene frequency is given by the appropriate solution of the equation

$$q = \frac{U_{11} - U_{12}}{(U_{11} - U_{12}) + (U_{22} - U_{12})}$$

The study of selection effects may be extended to cases with multiple allele ex linked allele auto polyploids and inbreeding populations

Gametic selection The effective rate at which the A and a gametes function may not be the am that is election may operate in the gametic in instead of in the diploid genotypic stage If the lective actions for the genotype aa for examp and gamete a are in opposite directions an equili rium may result

Balance between selection and mutation The are many different type of genotypic electio Two imple cases will illustrate the principle balance between election and mutation pressure

Selection against recessives Suppo e that th electi e value of AA Aa and aa are 1 1 an $1 - s$ where s is a positive fraction known as th election coefficient Then the new gene frequenc will b $q_1 = (q - sq^2)/(1 - sq^2)$ in the next ger eration o that the amount of change per ge eration is $q_1 - q = -sq^2(1 - q)/(1 - sq^2)$ A the same time if μ is the mutation rate from A t a the value of q will be increa ed by the amoun $\mu(1 - q)$ per generation At equilibrium th forces to increase and to decrea e the gene fre quency must cancel each other that is $\mu(1 - q)$ $= sq^2(1 - q)/(1 - sq^2)$ Solving one obtain $sq^2 = \mu/(1 + \mu)$ which closely approximates μ Hence $q^2 = \mu/s$ and $q = \sqrt{\mu/s}$ which usually is mall quantity When aa is lethal or unable to re produce $s = 1$ and $q = \sqrt{\mu}$ This explains the per sistence of deleterious recessive genes in a popula tion in pite of continuous selection

Selection a ainst dominants If the election is against homozygous dominants only the ituation is the same as in the previous in tance except for substitution of p for q and (mutation rate from a to A) for μ To bring out the distinction between selection against dominants an l that against re- ces i es take the extreme case in which AA is lethal the sele tive value of Aa is $1 - s$ and aa i the norm The value of p will then be so low that the usual genotypic proportions p^2 $2pq$ q^2 will take the limiting form 0 $2p$ $1 - 2p$ as q is very close to unity The increa e in q through election is approximately sp whereas the loss through mu tation from a to A is q = Hen e at equilibrium $p =$ /s This al e is much lower than $q = \sqrt{\mu/s}$ f r selection again t rece i es Thus election against dominant alleles is more effecti e than se- lecti n of the ame inten ity against re e sive Se lection against heterozygotes will eventually lead to the same limiting situation All the equilibrium alues supported by mutation pres ure are low but stable Mutat on pre ent complete extinct on of an allele

Random drift Th rand m dr ft f gen f q e m f t p p l t n s oft n call d th Se all Wr ght effect l ca f hi a aly s f it g fi Th g n fr q n y f any g r ti n is det rm n d by th unit g g m t pr li l by th parents f th pre ding g n rat n If th number f par ts l m ted and e titutes a ran d sampl of th ent e pop l tion th gen fr q ency f th ext g r t on will n t remain xa tly th m a that f th p evio gen r tion but will be s bj t to a ra d m fl t at n on a c t f th s mpl ng proces In a rand m mati g p pulat of N d id al h lf f whom are m a d half fem l a f m nta g th s pop l t n z the rian of the gen f q en y b d n $2N$ gam t $q(1-q)/2N$ Th gen fr q y may l m a l ttl high r lo er n th f ll w g g rat n The mall r th p pul t th gr t th a an Th ran d m p oces will nt t p at n ll gen r t f ffi ntly l g t m th al f q will reach ith r th term l v l 0 r 1 Hen th r d m d ft l d es nt lly t mpl t h mozy g f r sm ll pop l t n It n be hown that th l m t ng t of a h g th t t 0 r 1 s ach $\frac{1}{s}$ per gen r t n th t th t tal rat f

dec y f gen t sab l ty $\frac{1}{2N}$ p r gener

t Nat r l t h f d mer m ll s p lat d l es (f r ex mpl n 7 n m ta n s ley) w th h e t t r l t d with th en m t l d t t bat t t th theory f r d m (d pt) fi t

Th eff t ze f pop l tion th tn l numb f i d d l p d g ff pr ng nd th by p bl f th g t t t t n of th ext g er t Th d m m t g p p l t w th h lf m les d n ll fem les d p d ng th m mbe f ff p g id l d m d l A der t n f m th d al t t n ll h a different mpl g ria d s d ff ent r t f dec y Eq at g thes t th ta d rd r $q(1-q)$ $2N$ r th d l d

t l $2N$ n q lent N l t ed f th d l p p l t Th l tter mbe kn wn th ff t f pop l t n It ven ent to t m them t l descr pt f th gen t b h r f p p lat S m f th f ct th t tend to m k th ff tiv m ll th th t l h d g ze g en bel w

1 U q l mber f m les d fem les If M d F th espe mber th ff t N t mply $M+F$ b t d fi d by $1/N =$ $\frac{1}{4M}+\frac{1}{4F}$ d q l t $N = 4MF/(M+F)$ Th l g th d ffer betwee M d F th m ller th mber N mp d w th $M+F$

2 Un q l ze f f m lies If th g m tes d wn wh lly t d m f m th p ent th n mber f g m tes k t b ted by p ent w ll f m P d t b tio In h se th

ff t s the m a th a t al br eding size H wev r with ut perf t rand m ampl ng if th m n number f gam t s p r parent is $\bar{k} = 2$ th eff t ze s q al to

$$N = (4N-2)/(\sigma_k^2+2)$$

where σ s pre umabl y larg r th 2

3 Inbre ding If F s th inbreeding c eff cient f a p p l t n then th eff t ze s $N = N/(1+F)$

4 P riod c cha g i p p ulati s If N N N a e th respect s es f th g n r t o th a erag ff ct e f r th peri d appr imately eq l t th h rm ni m an f th s iz Th harm n m n s m h l ser to th m llest n mber f a r es than to th l g t n

Gene frequencies A t ti nary d trib t n f gen fr q en re lts fr m two pp s g f r es th y temat p es re (m tat n migr t n s l ti) wh h tend t mak th gene fr q ency tt in certa f ed l and th r d m vara t n d: t mpling wh h t nd to m k th g n fr q cy dr ft aw y fr m ny f x d l Th r lt f th pposing tenden es t n t ngl q ili r m l f gen fr q en y b t a tat n y d tr b tio f g n fr q en ies Th d trib ti m y b iew d in thr d ff r t way a th d tr b t f q f r g rt f r l en n a p p l t in l ng p riod f t m a th d t b ti n f th all l f eq en es f all loc l s t th m p es in n pop l ti n ta y g en t m nd finally a th d tr b t of q f n l en m g l rg mber f p p l tion of th am ze and w th th m p es es t a given t me

S Alleles

Under lect n p es r nd th ampl ng aria t n th d t b t n (m t n $\phi(q)$ s $\phi(q) =$ $C\bar{W}$ $q(1-q)$ wh r C s a n t nt $\bar{W}$ th a ag ftnes f th p p l t n d N th ff tiv ze of th p p l t n Th ex ct f rm f th d t t d pe d pon th l f $\bar{W}$ wh h a f t n f th l ct eff ent a w ll a th gen f q ency

If th m t t n m g tion pres or both th d t b t n f gen f eq en y s mply a β d t b t n $\phi(q) = Cq^{\mu}$ $(1-q)^{\nu}$ wher $\mu = 4N\mu$ $\nu = 4N$ f ther ly m t t n p $U = 4Nm\bar{q}$ $V = 4Nm\bar{p}$ if th r nly mi grat n pres d $U = 4N(\mu + m\bar{q})$ $V =$ $4N(+ m\bar{p})$ f th both Th ex t f rm f th β d t b t ndepend pon th al es f U and V When they maller th ty th p p l t n dered m ll when they a el to un ty th pop l t n term d ate n ze when they r m h l g th n unity th p pulat n dered l rg When th eff ts f m t t n migra tio nd l t n re comb ed th d t b t n functio

$$\phi(q) = C\bar{W} \quad q^{U} \quad (1-q)$$

F gu 2 h w m f th f rm f the d t bu t n der ri d t Th j nt d tr bu t n f m th n locus t lly ery m-

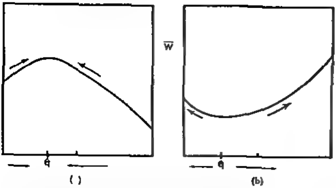


Fig 1 Diagram of the relation ship between the average fitness value $\overline{W}$ and q the equilibrium point for a (a) Stable equilibrium (b) Unstable equilibrium

value exists it must be the following solution of the equation $d\overline{W}/dq = 0$

$$q = \frac{\overline{W}_{11} - \overline{W}_{12}}{(\overline{W}_{11} - \overline{W}_{12}) + (\overline{W}_{22} - \overline{W}_{12})}$$

In order that q be a positive fraction the differences $W_{11} - W_{12}$ and $W_{22} - W_{12}$ must be both positive or both negative that is the selective value of the heterozygote must be lower or higher than those of both homozygotes For all other cases there will be no equilibrium except when $q = 0$ or 1

Stability of an equilibrium The value of $\overline{W} = p^2 W_{11} + 2pqW_{12} + q^2 W_{22}$ may be plotted against the value of q or p When W_{12} is greater than W_{11} and W_{22} the $\overline{W}$ curve has a maximum point (Fig 1) The q value corresponding to the maximum value of $\overline{W}$ is the stable equilibrium point This means that whether it is smaller or larger than q_3 the q value will approach q as selection proceeds from generation to generation A stable equilibrium of this type leads to balanced genetic polymorphism that is to the coexistence of alleles in a population Conversely if W_{12} is lower than both W_{11} and W_{22} the $\overline{W}$ curve has a minimum point yielding an unstable equilibrium the selection pressure will make the q value move away from the equilibrium value toward either 0 or 1 depending upon which side of the equilibrium the q happens to be Consequently selection against the heterozygote leads to the elimination of one of the alleles In more complicated situations there could be more than one stable or unstable equilibrium value in a population or both

The genotypic selection values W_{11} W_{12} W_{22} have been assumed to be fixed for each genotype but in nature they may vary in various ways In addition to the omnipresent random fluctuations the selective values may vary with the gene frequency itself For instance a genotype may be favored by selection when it is rare in the population but suffer a disadvantage when it is too common For such cases there will be an equilibrium yielding genetic polymorphism Let U_{11} a function of q be the varying selective value of genotype AA and so on Then the equilibrium value of gene frequency is given by the appropriate solution of the equation

$$q = \frac{U_{11} - U_{12}}{(U_{11} - U_{12}) + (U_{22} - U_{12})}$$

The study of selection effects may be extended to cases with multiple alleles sex linked alleles autopolyploids and inbreeding populations

Gametic selection The effective rate at which the A and a gametes function may not be the same that is *selection may operate in the gametic stage* instead of in the diploid genotypic stage If the selective actions for the genotype aa for example *and gamete a are in opposite directions an equilibrium may result*

Balance between selection and mutation There are many different types of genotypic selection Two simple cases will illustrate the principle of balance between selection and mutation pressures

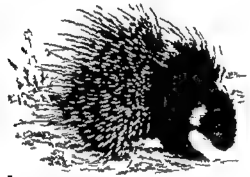
Selection against recessives Suppose that the selective values of AA Aa and aa are 1 1 and $1 - s$ where s is a positive fraction known as the selection coefficient Then the new gene frequency will be $q' = (q - sq^2)/(1 - sq^2)$ in the next generation so that the amount of change per generation is $q' - q = -sq^2(1 - q)/(1 - sq^2)$ At the same time if μ is the mutation rate from A to a the value of q will be increased by the amount $\mu(1 - q)$ per generation At equilibrium the forces to increase and to decrease the gene frequency must cancel each other that is $\mu(1 - q) = sq^2(1 - q)/(1 - sq^2)$ Solving one obtains $sq^2 = \mu/(1 + \mu)$ which closely approximates μ Hence $q^2 = \mu/s$ and $q = \sqrt{\mu/s}$ which usually is a small quantity When aa is lethal or unable to reproduce $s = 1$ and $q = \sqrt{\mu}$ This explains the persistence of deleterious recessive genes in a population in spite of continuous selection

Selection against dominants If the selection is against homozygous dominants only the situation is the same as in the previous instance except for substitution of p for q and ν (mutation rate from a to A) for μ To bring out the distinction between selection against dominants and that against recessives take the extreme case in which AA is lethal the selective value of Aa is $1 - s$ and aa is *the norm* The value of p will then be so low that *the usual genotypic proportions* p^2 $2pq$ q^2 will take the limiting form 0 $2p$ $1 - 2p$ as q is very close to unity The increase in q through selection is approximately sp whereas the loss through mutation from a to A is $q\mu = \mu$ Hence at equilibrium $p = \mu/s$ This value is much lower than $q = \sqrt{\mu/s}$ for selection against recessives Thus selection against dominant alleles is more effective than selection of the same intensity against recessives Selection against heterozygotes will eventually lead to the same limiting situation All the equilibrium values supported by mutation pressure are low but stable Mutations prevent complete extinction of an allele

h abs rpt on th s mat r I might b tt r be ealed vit fied n on. See CERAMIC TECHNOLOGY
[M C M]

Porcupine

Any of several la g rod ts with me f the hairs mod fied into po ted qu ll Th Old W ld f rms are t r trial noct al an m ls The ı _] N rth Am rica pe F ethi n dorsat m ı pla ed in the fam ly Er th o t dae It ı eb rae terized by t s bu t h dy and delil r te mo e ent t ı a bor l and a t e d ring th day Th p pn ı f u d all a r the o the n United St te m t f Ala k and Ca ada nd so th ard ı th m nt n



T p rc p F th d t m l gth t 3 ll
Fom P M D ed C ıs ll N t l H st ry
Cornell I

P up n d t ho t th ı q ll but an la h ut chls th th t fl s d embed many b bed q ill an d ary The e p te ted be l n m h of the N rth b au f ıl e ral ı em g cy f d f r men lo t in the d In w m a a th y a looked p n pest ber f th damage they d ı trees by gırdl them S RODE TIA [J D B]

Porifera

Th ponges a phyl m f th nimal kin d m h h ı ludes ab t 5000 d bed pe e The body pl of p g n que am ng n m l Cu e t f w ter e dr w th ugh mall po or ostia ı the p ng b dy a d] e bı w y f l rg p a g e lled l The l atı g f fl g b ll r cell or cho yt l c l d in h mbe n th t ı f th p e ma nt n the a r ucr nt S pp rt l the p nge t u p rd I by cal a eo s r l picul s by or n fibe s r by mb n t f rga ıc fiber l f u sp c] Th kel ton l p w th pport g net rk of g n fib rs h l ng been sed f baths nd l nı g p po es Be e f th p m ı e g n at p nge re l er t t zool g t a a d n d t d g th ıg f m lı ll l n m l See ANI IAL K. GDOM PARAZOA

Taxonomy Th P fe d ıded nt th s Hxa t ell da C lc ea and Demo-

pongiae on th b s of tl e skeletal tru tur A ta o mic heme of the l or fera foll w See ep arate arti le on ea h group

Cl H actınell da
 S bcla Ampl ıdı oph ra
  Order Amph d c a
  Order Hemid co a
 Subcla Hexa teropho a
  Order Hexa t n
  Order L chi ı a
  Ord l v cın a
  Ord r R ticulo
Cla Calc te
 Subcla Cal ın a
  Order Clathri da
  Ord Le cett da
  Orde l ha tro ıda
 Sul cla Calca on a
  O d Le ic len da
  Ord Sycett da
Cl s Dem p giae
 S bcl s T tra t n morpha
  Orde H m l rophor d
  Order Ch rı tida
  Orde Cla ax ell da
 Subcla Ceracti morpha
  O der D dr er t da
  Ord D cty r tida
  O der Hapl ler d
  O d r P cil cler da
  Ord r H l ho drid

General structure and cell types Tl e truct m a d f n ti n g f p ng ı m t ıly tud ed n y ung fresh wat ponge s they develop from dormant l d es ll d g mmule S ch oung spo ges po two d cr te c n l sy tem an ın h lant a d n e hal nt y t m wh ch are ı com m n at n w th ch th r by way of num ro s hambe l n d w th fla llated collar c ll The te or d rmal ep th l um m d up f fl tt ed p lyg n l ells c lled p na cyte and s p lo- rat d t ntervals by p e o tı thr ugh whi h wat r e te s the h lant an l y tem s ı lly by w y f large bde mal a t es The exhal nt nal a l l ned by pin c te

All othe c ll type in the p nge loc ted n the nhalant anal Th e ell m y b d l d nt tw te r e (1) tho with l rge l l t n l d (2) th se with r ller n cle ı la k g n le l with ery small u l ol In the former at gory e th h eocyte d n shap w tl blunt d pod a d hy lı ytopl m and m ny t pes of w de ing m b ytes wh h n med a ord g t th fun t on Th y a e called br mocyte l they b e th p me t anules z hl r ll e (n ell ıl r g een alg e) th o- cytes o ph rula ell f tl y r filled w th f od r a d t ph cytes if they re t g a u t t e lls f develop ng gg Mucu creting gl d ll p m bly de ı ed fr m amoeb cytes a e l mm tr n ges S l obla ts

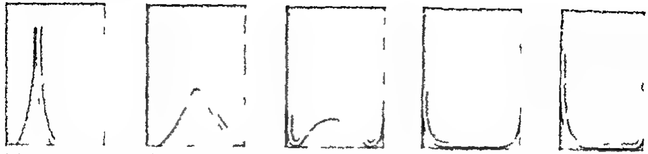


Fig 2 (a) Large population the distribution clustered close to the equilibrium value (b) Intermediate population a distribution of wide spread (c) Intermediate small population a distribution with some terminal fixation (d) Small population most genes close to fixation or extinction in the absence of systematic pressures (e) Small population with strong selection pressure

plicated Furthermore if the mutation rates and selection coefficients also vary instead of being constant the mathematical description of the stochastic process becomes very laborious and the forms shown in Fig 2 give only a first approximation to the real situation

The distribution forms of the gene frequencies depend upon the relative magnitudes of the various factors which bring about populational changes In large random mating populations all gene frequencies remain close to their stable equilibrium value which are determined by the counteracting but systematic pressures of mutation selection and migration There will be no further genetic change unless the environmental conditions change so as to define new equilibrium points Evolution in such large populations is guided essentially by intragroup selection and progress is very slow

In small and completely isolated populations most of the gene frequencies are close to 0 or 1 because of the random drift process which dominates the situation Selection is ineffective The loci are prevented from being completely fixed only by occasional mutations or immigrants The ultimate fate of such small homozygous populations is probably extinction because they are nonadaptive and unable to respond to new conditions

In populations of intermediate size all factors both random and systematic come into play and the population is more responsive to evolutionary change If a large population is subdivided into many partially isolated groups with migrations between them there will be some differentiation among the groups some of it adaptive and some nonadaptive but there is very little fixation The selection effect varying from one locality to another then operates largely on an intergroup basis which is more efficient than the intragroup selection within one single large population If the groups are small some of them will be eliminated by selection while others flourish This provides the most favorable condition for evolutionary success for the species as a whole The conclusion is that there is no one all important factor in evolution Evolutionary advance depends upon the interplay and balance of all factors *See* BIOMETRICS EVOLUTION ORGANIC GENETICS MUTATION (ONTOGENY) [CCL]

Bibliography R A Fisher *The Genetical Theory of Natural Selection* 2d ed 1959 J B S Haldane *The Causes of Evolution* 1932 C C Li *Population Genetics* 1955 G Malecot *Les mathematiques de l'heredite* 1948 S Wright Evolution in Mendelian populations *Genetics* 16 97–159 1931 S Wright The genetical structure of populations *Ann Eugenics* 15(4) 323–354 1951

Porcelain

A high grade ceramic ware characterized by high strength a white color (under the glaze) very low absorption good translucency and a hard glaze Equivalent terms are European porcelain hard porcelain true porcelain and hard paste porcelain *See* GLAZING POTTERY

Porcelain is distinguished from other fine ceramic ware such as china by the fact that the firing of the unglazed ware (the bisque firing) is done at a lower temperature (1000–1200 C) than the final or glost firing which may be as high as 1500 C In other words the ware reaches its final state of maturity under the glaze This makes for an exceedingly intimate bond between the glaze and the body which in turn gives high strength

The white color is obtained by using very pure raw materials the low absorption results from the high firing temperature and the translucency from the chemical composition the high firing temperature and the very thin sections in which the ware can be made

The term porcelain has been applied to the material used to make such things as electrical insulators and bathroom fixtures Very often these are made in a one fire process the glaze being applied to the green unfired ware where this is the case and high grade materials are used in compounding the body the term porcelain may be correctly applied However the pieces have no translucency because of their great thickness On the other hand the term porcelain is often applied to quite different ware For example zircon porcelain is used to describe a material made largely of zircon (ZrO_2 SiO_2) with small amounts of fluxes to yield

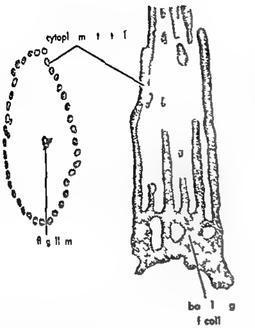


Fig 3 T rse (l ft) d t g t l (ght) s ct o gh th ll f a h cyt of f h w t spo g Elect m g ph (Aft R m t t l 1937)

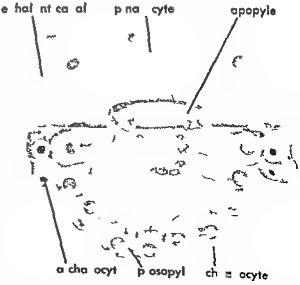
nd the ch g aize of th cul r pen g H nce food free te laden w th e r to y products earned fa away f m the sp ge s it l ave the osc l m a d lik ly t reent th ugh the ostu

Feeding and digestion Feed ng ct itie are best k own i f esh w ter sp nge n which the d rm l o t th nh l t c als the fl gell ted hamb s and the ch cyte ll st t te a set f ieve of d c e g me h si The d rmal ostia a e 50 μ d am te the pro opyl a e 5 μ in d meter and the sp s bet een tl e cyt pl m ten l s of the c ll ary fr m 0 10 to 0 15 μ Only the m ll t parti l s can ente the fl g llated hambe d come in c tact with the coll rs of th h anocyte The l tte t p the m ll part cl h h ed t the ll b dy d gested La g r p rt les wh ch h b bl to p thr gh the d rm l p ge t d by th h eocyt nd c ll cyt wh h f rm a et tl m n th nh l nt an l r by th ll b f the ho oc tes P t cl s too l t t th o t n be i g ted by the p a o yte f th d m l ep th l m Ob erv t s n th n t l f d f po ges e f w but c tt r d p rt gg t th t det t tt te th f t m ff d

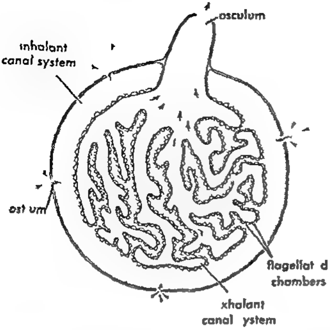
D rect b rv t n of l g f e h w te p ng nd at th t th h yt ar th h f ll respe bl f d g t e p Aft f d h ent ed th po g c l y h an yt s take p d th n rap dl l the p t cl wh h th y ha gested, nd t ha been s m d that th p t l a tra f red t h e yt d m ebocytes f d gestion. C ly gh h wes t d es

f the act vity of dig ti enzyme i a marine il ceo s p ge ind cate much higher proteolytic lipolyt c and carbohydrate-dec mp ing activities i choan cytes th i archaeocyt s Perhap a h gh r rate of dige t ve acti ity acc unts f the rap d d appe ra ce of pa ticles in the choano-cyt s Ob ervati s f the transfe of materials fr m the e c ll to archae cytes may ha e con cerned dig t l le products It i al possible that pecie d ffere ces in d ge ti e function ex st F ll w ng the digestio of the pa ticles in the ar ch eo yte the e ells migrate to the walls of the exh lant ca ls or t the de mal epithelium where nd gest ble material m oided f m bli te like ac u le

Reactions of sponges Studies f a hallow wa ter mari e l ce s sponge *Hym iac don helio phil* e hown th t th osc la clo e i p n e p sure to a a d wh n th p ge in q i et w ter T chi g str king e ther o c la or o tia doe n t ind ce lo O tia emain pen n air o wh n the p nge ts i qu t or lt lad wate The re tio s of this po g are tho ght to be s lely the re ult of the ntra t on f mvocyt s reacti g dir tly to e ternal stim l Mo m t a sl w a d t ansm ssion of timuli l mited R ct s f ula in the fre h water ponge *Ephydati flui tilis* d ffer omewh t from th e f the pre ous pec es O ula m in pe ru n ng r st ll w ter The o lar t be longate in st ll w ter d fl tt n t in t g current If a needle i rubb d a nd the edg f the cular p n g th or fi e co t act mmediat ly Weak el tr l st muli appl ed t tl e t p f n l m caus t t l and a wa f c ntr ctio runs down the nti e scul r tube T a m n f st mul to ne ghbo eg of the sponge w n t observed



Fg 4 D g m of fl g ll t d h mb f f h w t p g Ch mb h w pt l t h l t l i th d m (Aft K l



Fg 1 D agram of the can l systems of a young fr sh wate sponge cult red b tween cover slip and m c o scope sl de (After A k l 1950)

derived from archaeocytes secrete spicule and pon_gioblasts e rete pongin fibers

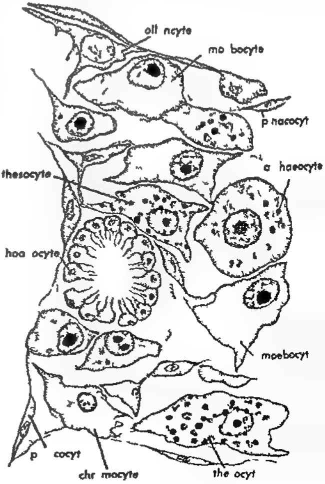
The anucleolate cells with mall nuclei include the pinacocyte mentioned above collencyte and choanocytes In addition to their function as epi thelial cells pinacocytes may be differentiated into spindle haped contractile cells called myocytes which occur in circlets under the epithelium around ostia and oscula Collencytes are tar shaped and ha e long thin protoplasmic pro longations which insinuate throughout the inhalant canal When they are bipolar collencytes are called desmacytes or fiber cells and are found in abundance in the cortex of some species of sponges Star haped collencytes with a vesicular or vacuo late cytoplasm are call d cystencytes The choano cytes are the most highly differentiated cells of the sponge Each consi ts of a small spherical cell body surmounted by a collar formed of many indi idual contractile cytopla mic tentacles and pro ided with a flagellum which extends from the lumen of the collar

The mesenchymal cells and the skeleton of the Demospongiae and Calcarea are surrounded by a colloidal gel called mesoglea secreted by amoebo cytes and po sibly choano ytes Ela tin fibers which help pro ide support for the sponge occur in the meso loea of most pecies

Water current system physiology The fla el lated chambers are hemi pherical in hape with a diameter of 40–60 μ in fresh water ponge They are compo ed of choanocytes firmly held to ether The uncoordinated beating of the flagella of the choanocytes creates the flow of water through the ponge Water enters the flagellated chambers from the inhalant canals by way of openings between choanocyte Two or three such openings (proso pyles) lead into each chamber Water lea es each chamber and enters the exhalant sy tem by way of a single larger pore (apopyle) through the epithe lial lining of the exhalant canal The lumen of an apopyle is ten times greater than that of all the pro opyles leading into the chamber thus water enters the chambers at a velocity ten times greater than that at which it leaves The collars of the choanocytes are o oriented that each directs its current toward the apopyle

A fall in pre sure takes place betv een apopyles and prosopyles and therefore the pro opyles exert a suction effect on the water in the inhalant canal *The effect of this lowered pre ure is tran mitted* to the subdermal cavity and water is therefore drawn into the o tia forcibly Food particles which may be at con iderable distances from the pores are sucked in along with the water

The incurrent canals are filled with a network of free cells which tends to decrea e the velocity of the water but the retarding effect of the e frictional forces is compensated by the resultant decrea e in diameter of the treams of v ater pas ing through the inhalant canals The velocity of current flow through the inhalant canals is twice as great as that through the exhalant canals which have mooth wall but are also greater in diameter An exce *pressure exists in the exhalant canals as a result of the pumping action of the flagellated chambers*



Fg 2 Type of c lls fo d in a f e h water sp ge as e n a c ct o th ough the nte o of th sponge (Afte M w 1936)

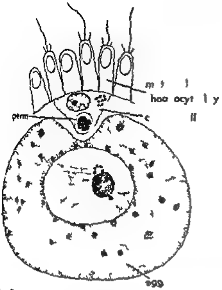


Fig 7 C c ll t m tt g pe m t gg C l ca eo p ge (Aft D b cq d T t 1937)

fr m the fl llated cells l the larv from choa cyt s, o l om a h eocyte The sperm ent the n t d e tly but th ough the nte m diary of a h ocyt wh ch l es ts c llar and flagellum and m gr tes f om th fl gellated ch mbe to a p tion adja ent to the egg Thi pr e s has be ob erv d in sev r l p cie f Calcarea a d Dem› pongi e a d is p bably f g eral o u ence n the e gr ups. The p rm wl ch l ts tail a d e l ges i e tu lly t nsfe d i th egg p a n bly foll wing the fu i of the a i c ll th the egg S e FERTILIZATION

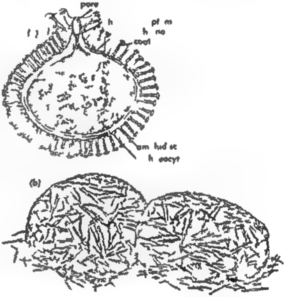
e be qu t de el pm nt of the mb y d larv s es somewhat n th se l cl es Th ir e sw m g fl g llat d larv a e th holl w mph bl tul l d ste e g t ul e Se CALCAREA D MOSPONGIAE HEXACTINEL IDA

As xu l p odu ti M y f e h t r a d m ma ponge d nt gr te with th n et f u f cable e ment l cond t lea ng beh d ed t o b d h h e c mpa t mas of ell l fly am bo yt ered by p de m l laye f som h ll w t r ma ne spon es th ent e spo g m n l e d i g th wint m nth but ch ng tat lly snt ma f m eb cyt Bcth r du t b d e nd the p rti lly ded fl en t t d adult sp nges c n de l p to fu t nal cl te ur ret rn l fa r ble c nd ti n

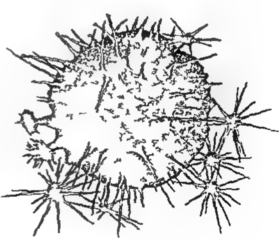
All f h w ter nd many ma in sp ng d e a x al r prod e b d es c lled gemm le part of th r l f cycle G mmule form d f ma f h eocyt s l den with food es rv n th fo m f l p d nd p t in In f e h w t r ponges th i ne ma s f c lls is e ded b l l l mn r c lls wh ch c t round the gemm le a d l le lay f p g n b twe wh h h te t c sp l are d p ted Th gem mule of m y n f ms p g a e alw n l ed in a p g n c t h h m y m y n t be p d d w th p ule Th mmule f fre h water ponge and a few mari e sp cies carry the spec es over pe iod of unfa orable environmen t l cond t on h as dro ight or low tem per tures du ing which t me the d lt col deg nerate Germin t n cf tl e gemmules curs up n ret rn of suitabl condition In many marine ponge gemmul a e f rmed at all ea on and tl e adult c lon e how no n l degener ti n

In a few pecie of Demosp ngiae and Hexac tinell da a xually prod ic d gemm le l cki g spongin at ha leen de ril ed a de el p ing int fla llated l r a ident cal n st uctu e to tho fo n d a a re i lt of exual proce e

Budding is an ther omm n type of a ex al re prod cti n n p nges In *Tethya* fo e mple groups f ar h ocytes migrate to the tip of p c



Fg 8 Sp ng g mmul ( ) Fr h w t spo ge g mm l opt c l s ct (ft 1901) (b) M f sp g g mmul rf c ew (ft H rtm 1958)



Fg 9 C l y f *T thy* ma l e p g w th b d l ot d t th t p of p ject g p ul b dl (F m Edm d n 1946)

Although neither of the siliceous sponges de scribed above reacted in any way to light it has been reported that in the calcareou sponge *Leuco solenia* bright light causes o cular constriction and a change in tube hape

Although there i little evidence from the behav ior of sponges that nerve cells are pre ent cytologi cal tudies suggest that such cells do exist Cells interpreted as being bipolar and multipolar nerve cells have been described from a wide variety of Demo pongiae and Calcarea In fresh water sponges and in a few marine Demo pongiae pe culiar cells called lophocytes have been described beneath the dermal meml rane The e cell which bear a proce s terminating in a tuft or fibrils may al o be nerve cells although it has been sug ge ted alternatively that they ecrete fine fibers forming a layer above them in the ca e of one pecies of fresh water sponge Unequivocal evi dence that ner e cells exi t in sponges can come only from physiological studies and reports ba ed on cytological work alone must be viewed with kepticism at pre ent

Skeleton Characteristic of ponges i the pres ence of a keleton of sclerites or of organic fiber or both Only a few genera such as *Halisarca* and *Oscarella* lack keletal elements The skeleton is of primary importance in the clas ification of sponges indeed the three clas es of the phylum are eparated on the basis of keletal structure

The hapes of the clerites or picules vary greatly and an elaborate terminology has been developed for them by taxonomi t An initial sub

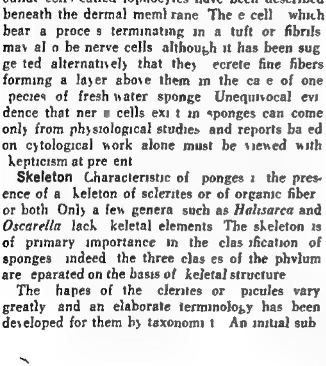


Fig 5 Suppo ed nerve cells sp ges (a) Two-c ll a c jo n ng p acocyte a d flag llat d chambe cal careo s spo ge (b) S so y cell nea su face co ected to n on mes chyme calcar s spo ge (after Pavans de Ceccatty 1955)

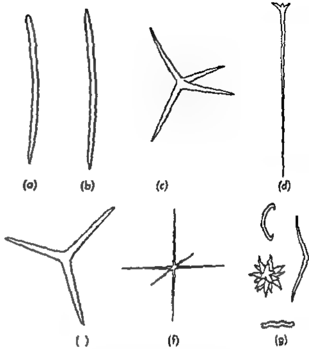


Fig 6 Sp cule types Monaxo s (a) mon ct nal a d (b) d act al Tetraxons (c) equ rayed and (d) t aene ( ) Tr ad ate (f) Triaxon o he act ne (g) M crosclere

division into megasclere and micro cleres i made on the basis of ize A more detailed nomenclature is based on the number of axes or rays pre ent an appropriate numerical prefix is added to the ending axon (referring to the number of axes) or actine (referring to the number of rays or points) Spicules formed by growth along a ingle axis are known as monaxons Such spicules are monactinal (pointed at one end only) if growth occurs in one direction or diactinal (pointed at each end) if growth occurs in both direction Tetraxons are spicules with four axes or rays each pointing in a different direction All four ray may be equal in length but often one ray is longer than the other three and the spicules are called triaenes Tri radiate (three rayed) picules are commonly found in calcareous ponges Hexactinellid ponges are characterized by the pre ence of picules with three axes (triaxons) meeting at right angles Such spicules have six rays and are al o called hexac tine

The fibrous keletons of bath sponges are com posed of spongin a s leroprotein in which are incorporated halogenated amino acids (monoiodo diiodo monobromo and dibromotyro ine) Spon gin is al o found in many pecies of Demospongiae with siliceous picules where it er e a an inter picular cement or forms fibers in wh ch the pic ules are embedded

Reproduction Both exual and asexual repro duction occur in sponges *The formation of a exual bodie* gemmules is characteri tic of all fre h water species

Sexual reproduction Thi type of reproduction occur in most sponges but it has been reported in only a few species of the order Chori tida of the class Demospongiae The germ cells may ari e

l ded plant g d rectly o concret d sks or str g g cutting al minum wire an hor d to raft of non sotts o p o ided with fl t g buoys

Organisms associated with sponges Sponges are p yed upo r g l rly by chito s snail d audibran h nd occa o lly by fi h d probably other type of an mal The l rvae of n u opt an vets f the f m ly S y d e (spong lla flie) l ve m a d feed pon col nies f fresh wate sponges Spo g also play ho t to myri d f nimal which live in th tu al ca t es of the sp ge or f rm burr s f their own Sea an mone z anth ds pel ch tes octop copepods ba na le amphi pod h mp b ttle star and fi h l e in spo ge l es b t the tur of their r lat hip with po ges h s b n l ttl explo ed The siliceous pong S b t d mun l s always l es hells occ p ed by h rmit ab a d pr d the crab with a c nt ally gr wi h Certain c abs plant o h ld piec of po ge n thei b cks nd thu bl d i to th r env ro me t Other encr sting a imal h a hyd oid bry z s and a cid ns wh h c mpet f p c w th ponges often o r gr at e grown by spo g lon es a the strug l

Zoochl r ll mmo ly liv i the amoeb cytes f f esh te p nge d m ny hall w w ter pecies B au e th algal cells fail to de l p tarch re rves whe l ing i p nge c lls n seem l kel th t the gars ynthe ized by the alg e are tilized by th p g cell Dying alg l ll are c umed by the amo b cyte Appare tly both th alg e d th p nge c n urvi e i d pendentl f h othe Y u g sponges are re ected w th lg e f m the wat r in wh ch th y

Certa marin sp ng are g larly filled with fil ment us gr o c ll e algae Th blue col r f some p ng ha be n att buted t bacte ia ln g in the ell The gnifi e of the e rela ti nsh i k wn Se ANIMAL KINGDOM AR CH FOCYATHA PARAZOA [W D H]

Bibliog phy L H Hyman *The I t b t* I 1 1940 v 1 5 1959

Porifera fossils

Th P (a ponge ha fo s l r e d e t d f m th Camb n to Rec nt t mes M re th 1000 g f f l p ge ha been de scribed f om th Pal zo M zoic d Ce o- Th pres rvat n of f s l p nge i l poo be se the sp ular k l t n u lly b comes d j nt d fte death Sp ge p l s e om } scatt ed th gh mar d me t ry ta b t the r d nt ficat n a d a gnment t est bl h d pe g ra f m l nd rd s e ll mpc bl d e t nl ll ad ed Some form h m sol d k l t u h a th l thi d Demospo g d tyid Hy l p ng d pha Cal p ng a l ft r cogn zabl f ssil

Geologic record A d g t M W de L n ben l th Camb n and o s di g pe ns l will l d wh h d c ta ab de f sponge com parable t that of the present Lith i t d w e comm n in the Middle Sil rian C l care have a range f om the Camb ian t the Re cent but we e not c mmo before the De onia d large numb rs of Hyal pongia were al pr e t in th Dev n The Ca bonif us cherts of Great Britain ar largely mp ed f sponge sp c les Ju as ic format ns f Eur pe ntain numer ous l th stid Dem pong a The Cret ce us was a t me of l rge numbe of Hyalo p ng a Th Ceno- z ic as emblage res mble th se of today a d mark cert n declin of number In m ny cas the f ssil sp nges are assoc ated with reef de elop ment Th pa tic l rly tr e of the S lur an lithi t ds nd the Pe mi n lith stids and calc re us pha etrone S e ORGANIC REEF

Types F il sp nge l ke their l ing repr sent tive are di ided into th ee cla ses the Cal spo g a (Calc ea) the Hyal po gia (H acti n ll da) nd the Demospong

The C lci pong a Th e C lcisp ng a (Calcarea) have cal eou sp ules made of cal ite or a ago- n te The pic l s are i the f rm of monaxon t irad at and q adri diates In the pharetro es the sp ules are f sed togethe int a more or less gid etw rk The maj ity of f ss l Calcispongia are pha eto es (ord Pharet nida) In many es the al reous materi l of the f il is re placed by sec dary sil ca The earliest kn wn r p- r ent t e of the la appe ed n the Camb ian but the g up is represent ted altho gh p rly ntil the Dev a

The Hyal spo gia The Hyalosp ngia (Hex a t nell da) ha e sil ceo p cule made of opal e s l ca Th rays f the sp cules e always at ight angle to h the and n mber 4 5 6 nd ely 8 ays The spi les ar interl ced r fused t th tip pr du ng pen a d r s nably r gid me hw rk The trat graph r nge f om Cam br n to Re nt Ex ellently pre erved glas sp ng a e k wn f m th Devo n of New Y k State

Th D mospongia The Dem p ng a ha e skele t ns m de of s l ce s picul of sp ng n or of l ce pic l s a d p ng n It s a e th t p c ul s f s me kind are not pr t The picul s can b m al tet ax l r rr la The st ma j ty of f l Dem p g a bel ng t the ord L thi t d The sp nge h e gul r nd kn bby s l ce spi l w th c mm ly bra ch ng o exp d d ext m t es The dj ent p c les nte l ck p od ng g d t ny k l t The th k d ppe ran e f th p c le i th ult of depo t n f s condary l a on ord nary s ngle o 4- ay d mall p c le The er ll hape of the sp g s fte gl bul r d a d n some f il forms utl e f h dv a als e p e erv d Th l th t ds ar rea on bly well pr rved in Pal ozo c ck but be me m t ab d t n th J a d C et c u Se CALCAREA DEMO S ONGIAE HEXACTINELLIDA [R J O]

B bl g phy R C M r (ed) *T tis on*

Fig 10 Spo ge fishing off Florida (Afte a m ral by S P Glas r i th Peabody M s um of Natu al H tory Yale Uni sity)

ule bundles projecting from the surface These buds fall off and form new individuals *See* REPRODUCTION ANIMAL

Regeneration Fragments cut from sponge colonies or pieces which break off accidentally in nature can reattach to the substrate and reconstitute fun tional individuals Suspensions of sponge cells prepared by queezing fragments of colonies through fine silk bolting cloth into ea water are also capable of reorganizing into functional sponges All types of cells normally present in the adult sponge except scleroblasts have been identified in the cell suspensions Reorganization of the cells to form functional colonies thus involves chiefly a migration of the cells to take up their appropriate positions in the reconstituted organism The pinacocytes form a peripheral epithelium around the aggregated cells and the various mesenchymal cells form the central mass The collencytes are active in reforming the inhalant and exhalant canals the latter of which become lined with pinacocytes Choanocytes group together to reconstitute flagellated chambers between the inhalant and exhalant canals Sclerobla ts form anew from archaeocytes Some workers have re port d that collar cells dedifferentiate or are phagocytized by pinacocytes or amoebocytes and are formed anew during the reorganization of the sponge

The initial aggregation of the di sociated cells to form masses results from random movement of archaeocytes amoebocytes and other cell types including choanocytes which have been ob erved to put forth p eudopodia and which al o move hort distances by means of their flagella As cells come into contact with one another they adhere po ibly as a result of antigen antibodylike forces The presence of homologous antibodies inhibits reaggregation Neighboring cell aggregates often adhere a well if they come into contact with one another

Mixed cell suspen ions of two species of ponges of different colors may result in an initial intermixture of the cells of the two specie but these later sort out so that the cell aggregates are eventually compo ed exclu ively or predominantly of cells of one species or the other

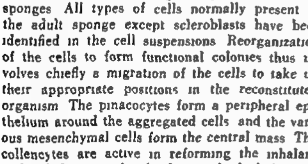


Fig 11 Zoanth ds l g n a sponge

Commercial sponge fisheries *Although* pla tic sponges now offer competition there is still a demand for natural sponges for u e by various artisans for urgical purpo es and for cleaning automobiles Commercially valuable sponges are harvested in the ea tern part of the Mediterranean Sea off the e t coast of Florida and off the Florida Keys in the West Indies and to a limited extent off the Philippine They are gathered by hooking or harpooning from a boat in hallow waters by nude diving a method u ed e pecially for exploiting cave populations in the Aegean Sea by machine di ing with the aid of di ing uits attached by a life line to an air pump and by dredging a wa teful method prohibited on mo t sponge ground

Artificial propagation of sponges ha proven feasible when erio s efforts have been made to do so In the Bahamas sponge cutting planted on natural bottoms or on concrete di ks in caref lly elected area yielded a harve t of 140 000 ponge during the years 1935–1939 Regrettably a di ea e pre umably cau ed by a fungu p ead th r ugh the We t Indies in 1938–1939 put an end to the cultiva tion expe iments and killed a large p centage of the natu ral pop ilation

Before World War II the Japane e had achie ed con iderable ucce in culti ating ponge in the Mar hall and Car line I l nd Th eir meth d in

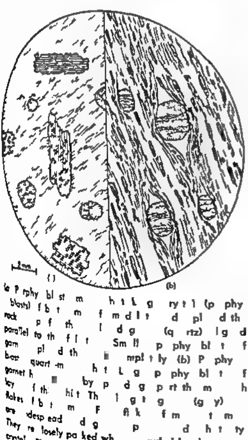
str g d th b d in the visibl range e re d ced t tw

Solut s of p rphy s in ga ic ol ent i r l a d xh b t tense red fl resce c with a gl em band in the 600 mμ ge wh le th e ctin li ht m y b f vi ible o n ltra let (So et b d) w elengths Fo t m t n of porphyrins, both pectr col imet d fl ori et m thods table S CHLOROPHYLL CYTOCHROME ENZYME HEMOGLOBIN For bio-synthes s IRON METABOLISM [R SC]

Porphyroblast

A l t ly l ry tal f med n a m t m rphic rock. The p ese f abunda t p phy bl t gives the rock p rphy bl tic text re Mineral f nd comm nly s p phyr bl ts cl de b tite garn t, hl t d t urol te kyan t ll m te and l t c d te nd feld p P phyro bl ts e g lly a few millim m ce ti met s a r b t ome attain d meter f er l h Th y m y b b ded by well d fi d rystal f es o th o tl m y be h ghly i regula ragged. V ry mm ly they are wd d with ti gr in f th m e al th t n the k So e po phyr bl t ppear t h h d de th ork l y s (f liat n) n a attempt t pro ide room f g th Othe clea ly tr ect th fol tion and appear to have replaced the rock The pre ence f ghostlike traces of foliation in the form of stringers and trails of mineral grain pas ng un nterruptedly through a porphyroblast is fu the de ce of replacement

Po ph r blasts ha e many fe tures in omm w th ph ry t b t a e to be d stingui hed from the l n by the f ct th t th y h ve de el ped n l d r k in re p t m t m ph sm Most m monly they de elop i h t d g ss during th late stag f recrystallizati n A the ock become re st t t d certain c mp nent m gr te to fa d t d ombine the e to devel p the large cry tals S GNEISS METAMORPHIC ROCKS PHE-NOCRYST SCHIST [C.A CA]



le P rphy bl st m h t L g ry t l (p phy blasts) f b t m f m d l t d pl d th rock p f th l d g (q rtz) l g d parallel to th f l t Sm ll p phy bl t f garn pl d th mpl t ly (b) P phy biotr quart m h t L g p phy bl t f garnet h by p d g p rt th m h lay f th hl t Th l g t g (g y) flakes f b t m F fl k f m t m are deep ead d g p d h t ty They re losely pa ked wh wd d by th g t crystal Elo gat g f l d tt m d both re lso l g d

Porphyry

An gneous rock char t ized by porphy t c tex t e wh ch large cryst l (phenocrysts) are e closed i a m t f ery fine-g d to apha tic (not visibly crystall e) material

P phy e are g lly d sting hed f m other p phy t c ocks by th bundance of phe-oc y ts and by the cu renc i mall i t us n b d es (d ke and sill) f rmed t shallow depth w th n the earth In this n p phyri s are hypa by l k

Comp sit lly porphy ange widely b t va t m y be d t guished by prefi g t the te m the comm n rock n me whi h the p phyry m st l ly e embl (uch a gr nit porphyry by l te p rphy y sye te p phyry and t a hyte p phyry) S IGNEOUS ROCKS

P phy n are g d t n l t pl t e r ck on th e ha d d t l n ro k o the other In the g t l f r mpl porphyr t c typ may ll ec g d (1) porphyrit c g an te (2) g nite p phyry (3) hy lit p phy y (4) p phy t c rhy l te (5) n ophyre and (6) p phy t c b d n r p phy t c pit hst ne

A k of g n tic mp s t w th b da t l p ph y t of q t nd lkal feldsp in a fi e-g ed m t f m l r mpos t on s p phyry m re p fi lly g nite p phyry G n t p phyry p e i t p phyr t c g an t s the g e of the mat es d b n d f phe o y ts d n Th s the r ck b me g ite m p fi lly a porphy t n t G te p phy y pa i t rhy l t p phyry th g ai e of th m t i nd ab nd n f ph ocry t de Th p n pal d t t n b twee hy l te p phyry d p phy t hyol te th m de f c Rhy l t p phy y s n t p phy t hy l t t n e P phy t k w th gla m t e k w a t o phy e W th de ea n mb f phe o ry t t phy e p e to p phy t b d o p phy t p t h t e

The ph ry t f p phy t l gely f qu rtz d f ld p Q rt w ll f rmed (e hed l) h ag al b pyr m d wh h th t u der the m c n e hib t d m d

1955 V J Okulitch and S J Nel on *Sponges of the Paleozoic* Geol Soc Am Mem 67 763–770 1957

Porocephalida

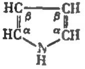
An order of the class Pentastomida in the phylum Arthropoda The two families comprising this order are the Porocephalidae with 5 subfamilies and 12 genera and the Linguatulidae with 2 genera Distinctive features of this order include four legged embryos po terior lo ation of the female genital pore highly developed head and hook glands and a long and winding ovary

The Porocephalidae are cylindrical with club shaped ends They are provided with either simple hooks or double outer hooks This family includes the greatest number of pentastomid species The adult form are parasitic in reptiles the larval and *nymphal forms infest mammals*

The Linguatulidae are flat in shape with simple hooks in the adult state and binate hooks in the nymph The first described species *Linguatula serrata* commonly occurs in the nasal cavities of dogs in Northern Europe For this species the larvae are approximately 5 millimeters (mm) long The adult males measure 20 mm and the females 130 mm in length *See* PENTASTOMIDA [H R H]

Porphyrin

A class of red pigmented compounds with a cyclic tetrapyrrolic structure in whi h the four pyrrole rings are joined through their α carbon atoms by



Pyr l

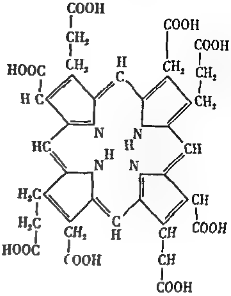
four methene bridges (=CH—) The porphyrins form part of the active nucleus of chlorophylls *a* and *b* hemoglobin myohemoglobin cytochromes and the enzymes catala e and peroxida e The parent substance i synthetic porphin in which the hydrogen (*H*) atoms in the eight β positions on the pyrrole rings are unsubstituted Naturally occurring porphyrins differ from porphin and from each other by various side chains in the eight β positions Some typical porphyrins are l sted as follows

1 Uroporphyrin occurs naturally and may be synthesized The sub tituted groups are four carboxyethyl (—CH_2—CH_2—COOH) and four carboxymethyl (—CH_2—COOH)

2 Coproporphyrin occurs naturally and may be synthe ized *The sub tituted groups are four* carboxyethyl and four methyl (—CH_3)

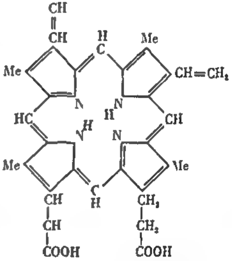
3 Etioporphyrin a synthetic porphyrin has four ethyl (—CH —CH) and four methyl groups

4 Protoporphyrin occurs naturally and may be synthesized The substituted groups are two car



Urop pl yri type I

boxyethyl four methyl and two vinyl (—CH= CH)

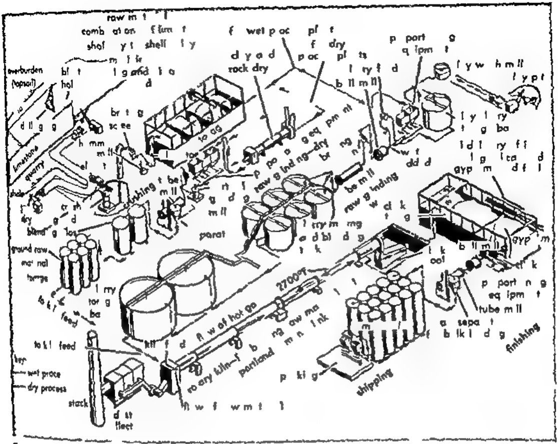


P to orp y typ IX

5 Hematoporphyrin a synthetic porphyrin has two carboxyethyl four methyl and two hydroxy ethyl *(—CH —CH—OH)*

Porphyrins with two kinds of ub tituent groups such as uro capro and eti porphyrin have four structural isomers known as type I IV Only type I and III are found in nature The number of possible i omers for porphyrins with three different substituents for example prot and hematoporphyrin is 15 (types I XV) Prot porphyrin type IX has been identified in nature in the free *form and in heme which is the pro tl etic gr up* of hemoglobi is and other heme proteins Protop r phyrin type IX correspond t synthetic etiopor phyrin type III

P rphyrins dis ol ed in organic lvents and in dilute alkali ha e a typic l al rpti n pectrum exhibiting four bands in the visil le range and a very strong Soret band in the near ultra iolet In



Flow h rt (pl fi d) h w g th man f ct e of p tl d m t f om qu ry g t f n l h pm t

P rtl d m nt ts u d in many d ff nt type co tr cti n The e patt rn s pp oximately as f s highw y 20% n es dential on s u n 20% n side tual b ld g 15% m l tary co tru t n 10% publ c ut l t e 10% sewer d wate k 8% other us 17%

[W L E]

Portuguese man of war

A l g floating highly ompl col al mar ne an m l of th cla Hydr phyl m C elen terat Th most p om n t fe t e f the Po tu g man-of s i th l ge fl at or c tral h d lt 8 10 i l g b r g a l l k c e t Th f at be t f lly i d nt sh w ng bl es p ks p pl d carm n Be ath th flo t e t c t es f th d t t type n t t e thers fe ers a d t ll ther u p du t Th t t les arry m r u t g ng cell c lled mat t ap bl of nfl t g a p nf l b t a lv f t l ey rs Th t t cl f a larg p m may b ver 60 ft l g The m l f ed p ima il n fi h b h a e fi t ubd ed b th nemato y ts A ho gh most b d nt n the G lf f M x o t l w t t oc s n nmb r n the C lf ream f th Atl t O nd f equ ntly dr fts orth d l omed ta e A sm ll pe f fi h f the gen s Nom us lives am g th t tacl s f th P rt gue m n

Th Port g man- f w Phy l p l g le gth of b dy t 10 (F m J G W od P p l N t l H t ry P rt d Coat)

square or hexagonal outline Individual pheno crysts may show more or less rounding or resorp tion with deep embayments Alkali feldspar is usu ally euhedral sanidine orthoclase or microperth ite *Plagioclase occurs more in association with* phenocrysts of hornblende or other dark colored (mafic) minerals Porphyritic rocks with predom inantly mafic phenocrysts (olivine pyroxene am phibole and biotite) are commonly classed as lamprophyres *See* LAMPROPHYRE

Outside the United States *it is common to fur* ther re trict the term porphyry to those rocks in which the feldspar phenocry ts are principally al kali feldspar Rocks with dominantly plagioclase phenocry ts are called porphyrites

Porphyries occur as marginal phases of medium sized igneous bodies (stocks laccoliths) or as apophyses (offshoots) projecting from such bodies into the surrounding rocks They are also abundant as dikes cutting compositionally equivalent plu tonic rock or as dikes sills and laccolith injected into the adjacent older rocks [C A CA]

Porpoise

Any of several small whales of the family Pho caenidae found in all the oceans of the world except the polar waters The porpoises like other whales have no hindlimbs The forelimbs are re duced to small paddles the caudal region is modi fied into a pair of lateral flukes the neck region is shortened and the eyes are small Porpoi es have many small teeth set all along the jaws the dorsal

The common porpo e Phocae a pho a a length to 6 ft (F om E L Palmer F eldbook of Nat ral H tory McGraw H ll 1949)

fin is low or lacking the head is blunt and rounded without a beak Porpoises attain a maximal length of 8 ft and weigh not more than 120 lb The harbor porpoise *Phocaena phocaena* is common along both coasts of the United States *It* is 4–6 *ft long* black on the back with pink id s and a white belly The Pacific race is considered by some stu dents to be a eparate specie *P iomerina See* MAMMALIA WHALE [J D B]

Portland cement

A hydraulic cement consi ting mainly of calcined silicates of calcium *Portland cement mixed with* water and and gravel (or aggregate) or other substances is a common material of construction *See* CONCRETE

Manufacture The illustration shows the manu facture of portland cement The raw materials are principally calcareous materials such as limestone marl chalk or hell and argillaceous materia such as clay shale or iron bla t furnace lag Th chemical limitations in the pecifications are uc that the proportions of calcium oxide ilica alı *mina and ferric oxide must be maintained withı* narrowly defined limits and other constituent uch as magne ia and alkalie mu t not excee specified limits These re triction nece itate a times the introduction of other material such a high calcium limestone and tone or iron ore T *produce white portland cement materials of ver* low ferric oxide content must be u ed The ra materials are blended and ground to a finene approximately the same as cement The raw mate rials may be ground dry (the dry process) or i *water (the wet process) The pulverized mixture i then burned in large rotary kilns at 2500–2800]* to produce portland cement clinker The fuel ma be coal oil or gas

Calcium sulfate (gyp um) is added in a quan tity ranging from 4 to 8% by weight of the clinker *It serves to regulate the setting time trength and other properties of cement water mixture* Th clinker and gyp um are then ground to su h a fine ne s that about 90% will pass through a no 20C sieve that is a wire or cloth mesh having 200 open ings per square inch

Types of cement Heat is liberated during the proce s of hydration and hardening of cement wa ter mixtures It is desirable to minimize thi heat liberation in mass concrete uch as large dam o as to reduce the thermal tre s and cracking that may occur as the exterior urface cool while the interior of the mass is at a higher temperature Some types of cement are su ceptible to chemical reactions with sulfate waters which can cau e ex pansion and deterioration of mortars and con cretes The heat of hydration and sulfate re i tance are controlled by adju ting the chemical composi tion of the cement High early strength i attained in part by composition but largely by finer grinding of the cement

The American Society for Te ting Materials specifies the chemical and phy ical requirement for fi e types of portland cement and de cribe the purpo e of each

Type I is for u e in general concrete con truc *tion when the pecial propertie pecified f r type* II III IV and V are n t re q i ed

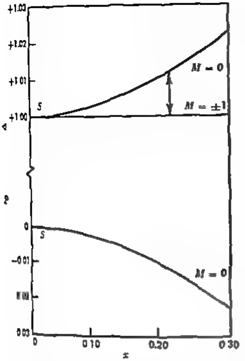
Type II is for use in general concrete con truc tion expo ed to moderate sulfate actio or where moderate heat of hydration is required

Type III is for u e when high early tr ngth i required

Type IV is for u e when a low heat of hydrati n is required

Type V is for u e when high ulfate re i tance i required

There are al o a number of m d ficati n of p rt land cement or mixtures containing p rtland ce ment *S e* AIR ENTRAINING PORTLAND CEMENT CE MENT



Zeema gy l l of po t m i t g nd 1 st t Th q t ty Δ th hyp rf t ct separatio betw th S d th S t t f p tron t x st t m g t f ld Th M al d ignat th g t b t t $= 2g_n\mu_0H/(h\Delta)$

(ect) b dete m ed f m th H m lt n an term

$$H \quad \mu g\ s \quad H + \mu_0 g\ 1 \quad H$$
$$+ \mu_0 g\ s \quad H + \mu_0 g\ 1 \quad H \quad (4)$$

m b h l(2) f s t the elect (p t on) μ is th B h mag t (= $\hbar/2m$) g_l s the orbit l g al (= 1) m th lect on spin g l e [2(1 + /2 − 0 328 α /−)] g_n = g l the elect n (p tr) o b t l an gl m m t m s the ele t n (p t o) spin gula m m tum d H th t n l magn t fi ld t s ty P t m ha n p ma ent m gn t m me t b t th can b mag netic m m t duced by the xt al m g et c fi ld d h n e e gy le el depe d n H which p f H Th e gy le el d g m f th g d t te f p t um a m g et field is h n th figu F m m m t f th f g y of th Z em t ns t ΔM = ±1 bet een th mag t c ble l f th S tat t h p fi tru t re t rval Δ h s b d t ed t be

$$\Delta \quad (2\,0333 \pm 0\,0004) \times 10 \quad M \;/$$

T m t l l g with th th etic l t t f th q t m l t rgr m t t tute the p p l d s tlem dy am s f the two-

Decay Pos t nium s an u table tom d a nih l tes w th th emis i n of pl oton From ts gro d S t t a p troni m at m t re t decays into two γ y each ha i g an e rgy f mc (~510 k v) w tl a dec y rate of 8 03 × 10 sec from its ground S tate po itr i im atom at re t decays to three γ ray wh e ene gie t tal 2 mc with a decay rate f 7 21 × 10 ec [V W H]

B bl og aphy E D Benedett a d H C Corben P tronium *An R t Nt l S* i 4 191–218 1954 M De it ch Annihil t on of positron *Prog i Nucle Phys* 3 131 138 1953 S Fluegge (ed) *H ndbu h der Phy k* vol 35 1956

Postglacial vegetation and climate

The Plei t or Gl ial Epoch at pre ent esti mated a th la t 1 000 000 ye is le rem k ble fo d al ev lut ary cha g in plant lif th n f r repeated h ft of posit o becau e of cl m t c hange a d the res lt g ice mo m ts The n flue of these cha es is kn wn to have e te ded f r beyond th l mits f gl iation pa t cul ly n mo nt n u reg who e belts f ge tat n mig t d p and d w e p to climate The t t of ho t l hifti g far beyond the ce bord s i t yet resol ed S GLACIAL EPOCH PLEISTO ENE

Plant migration and glacial stages The p nt d t b t o of g t t on ce tainly outside th t op p es the dju tm t th t f ll wed the la t maj d a ce kn wn as the Wiscon i ge n North Ame The ret eat of the W n ice f m th t em p i n t p d in outh ern Oh o s m 18 000 yea g wa p lsati g in ch r t r b g m k d by lternati g pe d or sub t ge of t eat and ad Twel e th u sa d y a g t had t e t d then e d a ed to Port Hu on Mi h g Some 2000 yea lat it had g retreated a d d an ed to th n th hore f Lak Er e F om th V ld t ge t the b gan a p d retr t to it p e e t p s t w th a po bl p u C nada me 6000 years

Th E p an eq le t f the V ld ra the Fe c d n ma ked by the north mo t n sp m nes d ted between 10 000 a d 11 000 y ag b eq ent t m i b t arily c n d d po tglac al n Eu p I Am ica i ap more ent to spe k f p tgl t n t m w th ef re ce t pec fic l al t si fo e ample C l mbu Oh a d Lon I la d N w Y k we e e f e l ng bef e Detr t Mi h an a d Ha tf d C t t d ha h d a sp nd ngly l ger eg t t to y

The ea l e ide of pl t m g tio nd he f f d l m t e ch w d ed f om m p pl t r m a d fr m d j t or deta hed spe e a d mmu t es f l ng pl nt n w f d t de th cha stu ng Clas mpl the mm n t f bog pl ts n thern i ffi tie th t orc w th n the d id

of war with apparent immunity The fish seems to be accepted and protected by the man of war as a lure to attract other larger fishes The *Nomeus* in turn is thought to feed on craps left over from the kills made by the man of war This is frequently cited as a prime example of symbio is Some workers think that *Nomeus* is immune to the stings of the Portuguese man of war because it feeds on the animals caught in its tentacles *See* HYDROZOA

[J D B]

Positron

An elementary particle with mass equal to that of the electron and positive charge equal in magnitude to the electron s negative charge The po itron is thus the antiparticle (ch rge conjugate particle) to the electron (*see* ELECTRON ELEMENTARY PARTICLE) Its existence was predicted by P A M Dirac (*see* QUANTUM THEORY RELATIVISTIC) It was first observed by C D Anderson in 1932 The positron has the same spin and stati tics as the electron Po itrons like electrons appear as decay products of many heavier particles electron positron pairs are produced by high energy photons in matter *See* PAIR PRODUCTION (ELECTRON POSITRON)

A positron i in it elf stable but cannot exist indefinitely in the pre ence of matter for it will ultimately collide with an electron The two particles will be annihilat d as a result of thi collision and photons will be created However a positron can first become bound to an electron to form a short lived atom termed positronium *See* POSITRONIUM

The virtual production of electron po itron pairs by an electromagnetic field produces a polarization of the vacuum This results in eff cts such as the scattering of light by light and modification of the electrostatic Coulomb field at hort distances *See* QUANTUM ELECTRODYNAMICS [C J G]

Biblio raphy W Heitler *The Quantum Theory of Radiation* 3d ed 1954 J M Jauch and F Rohrlich *The Theory of Photons and Electrons* 1955

Positronium

The bound state of an electron and a positron Positronium was discovered by studies of the so called annihilation radiation from positrons stopped in ga es It is formed in a collision between a po itron and a gas atom which results in th capture of an atomic electron by the positron The positron is the antiparticle to the electron and hence has an inertial mass equal to that of the electron a positive charge equal in magnitude to the electron s charge and a spin of $h/2$ where h is Planck s constant h di ided by 2π *See* POSITRON

Positronium is of particular interest because it is the two body system to which quantum electrodynamic is applicable and its study has erved as an important confirmation of the theory of quantum electrodynamics See QUANTUM ELECTRODYNAMICS

No states of positronium other than the ground $n = 1$ state ($n = 1, 2, 3$ being the principa quantum number) have yet been found Studies o positron annihilation in solids and liquids indicate that a perturbed form of positronium exists und certain conditions

Energy levels The approximate energy levels of positronium can be calculated from the Schrodinger equation with the nonrelativistic Hamiltonian H_0

$$H_0 = \frac{p_1^2}{2m} + \frac{p_2^2}{2m} - \frac{e^2}{r} \qquad (1)$$

in which $p_1(p\ )$ is the electron (positron) linear momentum m is the mass of the electron or po itron $-e$ is the charge of the electron and r is the distance between the positron and the electron (*see* QUANTUM THEORY NONRELATIVISTIC) The energy levels of the bound states are given by

$$W = -\frac{\pi^2 me^4}{h^2 n^2} = -\frac{r_y}{n^2} \qquad (2)$$

The quantity r_y is defined by Eq (2) as the Rydberg constant for positronium (*see* RYDBERG CONSTANT) The binding energies W of positronium are one-half the corresponding binding energies of the hydrogen atom (if the proton-to-electron mass ratio is con idered infinite) In particular the ionization energy of positronium (the binding energy of the ground $n = 1$ tate) is 6 8 ev

Fine structure to the energy levels of positronium as given by Eq (2) of the order $\alpha^2 r_y$ [$\alpha = e^2/\hbar c \cong 1/137$ is called the fine structure constant] arises from relativistic effects including the electron and positron spin magnetic moments and from the interaction with the electromagnetic field which causes electron positron pair annihilation Since the electron and po itron intrinsic pin angular momenta are ½ in units of $\hbar$ the total spin angular momentum quantum number S of positronium can be either 0 (singlet tate parapo itronium) or 1 (triplet tate orthopo itronium) For each n value positronium can exist in either a singlet or a triplet tate The orbital angular momentum quantum number L can a sume the values $l = 0, 1,$ $n - 1$ In particular the ground $n = 1$ state of positronium is split into two levels S_0 and S_1 which are separated in energy by the amount

$$W(^3S_1) - W(^1S_0) = \alpha^2 r_y \left[\frac{7}{3} - \frac{2\alpha}{\pi}\left(\frac{16}{9} + \ln 2\right)\right] \qquad (3)$$

The term of order $\alpha^3 r_y$ ari es from virt al quantum electrodynamic proce es Thi energy eparati n often called the hyperfine tru ture of the gro nd state of positronium corre p nd to a frequ ency difference Δ of $2\,0337 \times 10^5$ Mc ec *See* FINE STRUCTURE (SPECTRAL LINES) HYPERFINE STRUCTURE

The dependen e of the energy level of po itronium on an external magnetic field (Zeeman ef

Posture regulation of

The co tract n of mu cles rves not o ly to mo th joint in loc moti n b t al to maintain the j ma fixed posit on d r g the a sumpt on of st onary att t de p t res (se MOTOR SYS-TEM) A imple exampl f the r l of the

c lar sy tem in ma nta n po ture en hen a man mai t i a sta di g po ti n When the bod is i th p i ht p t on gra tat onal f rces te d to cau e the jo nt t flex and th l mbs to coll e u d the we ht f th l dy Th t prevented b the o ta tion of th xten r mu es f th l e limb that g a itation l fo ce r co nte act d nd the upri ht p tion i na n tan d. The musc l ontract on required fo erect stud g t ined by effe a t o and q ire a e a u eff rt r atte t on nterr ption f the nerves su ply g the leg m cl de t oy not nly the bilit t walk but l th bility to tand (se REFLEX, C O DITIONED) Th refle mech m r gul ting po tur are highly fl ble o but pa e act chang s n po tion f th body a t ome h n e the p ttern f m scl cont act n whi h re ult tan e at t des ppro iate to th ew hanging o i nia ton f bod Th refle e m d at ng th r a t on a kn wn s p tu al fle es

Decerebrate rigidity Th p n l r flex me h m respon bl f t nd ng may b tud ed in t t a m s b t i be t een n de ebrate prepar tion n animal wh h th b a n tem has been compl tely tran e ted b tween th u e i r d u l rs coll l to pr du e t t l latı n of t l w b ain tem med lla a d p al c rd fr n th tral (a te) brai t uctu The at mimes uch rad al rgery surpr ngly well d pr th occurr f ert n neu ol g al defi ts th vital fun t o f resp ati n and i ula ern a e adeq ately ma ntained by th e rema ning isolated neur l t u t res. A t ki g feat re f th dec brate pr par t s an exagg r ted post refl x d crib d b C S Sh r ington n 1898 The limb ume a po t o f rigid xte on and t ly es t p fix n f th j nt Onc b th fle ed th j nts re ea ly e tend d P t ation f th mu cles re e l th t th r gid ty s ma ed b a t e c nt act n of th ext n r les f the l mb

E ensor r gid ty uff t t pport the ht f the body d wh the n m l i plac d on feet t d ig dly f t i l ghtly pp t d from th de t p es nt to pl g M cl othe th those f the l mb r s mila ly ff ted th b d k h ld ect w th th h n up the jaw s and t ghtly h t and acti ely r i ts ff rt to open t d the t l l tu tand re t Th mu head f l y g rig d ty e th ant g a ty mu cles that th m scles h h n th n ma l up ght the ppose th gr t t n l fo ce te d g to w ll p f th b dy D e l t n n th th a m l whi h esists gra ty with ts

flexo mu cles it hangs up de d wn from bran he cau s a flex r rig d ty

Dec rebr te r gidity is thus a car cature f tanding Th e exa g r ti n s d to the release of pin l moton u on from i l b t ry imp l es whi h riginat in sup a egm ntal structure and nor m lly de cend th ough th pathway wh ich have been inte r pted by the brain tem transecti n The r le f the e upr egmental i u ture i di u ed below Decereb ate r g dity s a r flex that req i e gmental aff nt inp t t m intain the di charge of the m t neur n s pplyi g th af fe ted ntigr v ty m l Whe the d r l spinal r ots c n eying en rs imp il e fr m a ri d limb t th pi al cord a e d ided igidity d appe rs ard the l mb be om s flacc d S mila ly entral ro t ecti n al) he r g d ty by int r upt ng the effe ent part of th e reflex a

The or g n of the fferent impul e wh ch m i tain decerebrat rig dity not in e ept rs of kin f j ints or of tend ns becau t pe si t un abated after emo l f k and aft r local ane theti which ender e ept r n en tive are injected into jo nt and te d n The re po l le re eptor a e the m cle th m el es and the adeq ate stimul s for the r x it i on i tret h of th e m le b au e th y thu regi ter nt oc c rring i the b dy t elf they are la ed a pro prio r t pp ed t ste o ept r (f e am ple ret nal a d ta t le re pt rs) wh ch ea t t ternal ents Th imp l e ge erated in th tret h re ept f ant a ity m le by gra ita ti nal for es (wh h tend to au e th l mb t fl an l th u t etch the e ten o m cl) a e tran m tted t the p l d ver aff r nt fibe of the d rs l r ot Th tretch s n it aff re t m ke d ect c n ecti ns w th the moto e r ns suppl ing the tr t hed mu cle a d n tiate in them a effer nt d harge wh ch elicits mu c l r c nt act on op po ng elongation of the m scle and th s ma ntains up ight po t re Fu th r th effe ent d charge i gr d d that refl x mu c l contract on i thr ugh a n ide able ange f t etching f rce uffic nt to mainta the m l at fixed l th a d thu to pr nt oll p e f the l mb

F exampl unburd d t nd g only the w ight of the b dy t nds to buckl th knees and tretch th k ee xt n ors Th m ld degr e of t etch ex t only the st etch r cept r of l w t th e h ld a d the e r pt d ch rge at r la n lv low t C n q tl th k d ffe ent d ha g a d th r lt nt r fle nt a t j p ly uff i t to k ep the j i t t ight If I s l d pl d p the l ld the add t al tret h n for e au a t e tr t h p t r to d scha g mpul e at h h r t and al o el t d ha g in th h ghe th l old e p t s wh h we e p u h l nt (e tment) Th r a d affe e t d ch r e a ti at s mo m to ur d dr th m at h gh r r t o that the r lt nt flex ntra t n i n re ed uff ll t ff t th n wly imp ed l u den Th

ous forest region These are properly considered as remnants left behind from a colder time

The record was complicated however by the presence of disjuncts appropriate to warmer and drier conditions than now exist such as prairie inclusions in the deciduous forest regions of North America and Mediterranean plants in northwestern Europe Furthermore the European peat beds contained strata indicating that the time of glacial retreat had been marked by fluctuations in moisture and temperature and was not a simple gradual warming down to the present

To reconstruct an orderly history requires the study of representative plant remains in close stratigraphic sequence These requirements are met by the fact that pollen grains are well preserved in lake sediment both inorganic and organic The statistical study of such evidence begun by L von Post in Sweden in 1916 is the most substantial source of present information *See* PALYNOLOGY

Broadly speaking the results obtained confirm the hypothesis advanced by the Norwegian Axel Blytt in 1876 on the basis of his study of Scandinavian peat beds There are however many local modifications due to soils topography rates of plant migration and masking of minor changes by climatic extremes Blytt s ideas were for these and other reasons the source of prolonged controversy He divided postglacial time into the following phases Pre Boreal cold and wet Boreal cool and dry Atlantic warm and moist Sub Boreal warm and dry Sub Atlantic cooler and moist Recent work suggests that the Boreal in northern Europe was warmer than the Sub Boreal The reverse seems to be true in North America but further study is needed

Until recently the only method of dating these changes was by means of banded sediments or varves and by estimates of the rate of sedimentation in particular of peat formation Both methods considerably lessened the previously accepted time span and gave results of an order of magnitude now confirmed by the precise physical measurements of radiocarbon change

Vegetation and climatic phases Four general principles emerge from the data now at hand (1) The general pattern of climate following ice retreat is that of an irregularly sinusoidal graph so far as moisture is concerned (2) This pattern occurs against a background of temperature gradients (3) The *maximum number of vegetation* and climatic phases occur near the glacial boundary the number decreasing toward the present areas of remnant ice (4) Moist phases appear to coincide with time of ice accumulation and advance dry phases with ice wastage and retreat Whether or not these phases are reversed within the tropics is now under discussion

Also under discussion is the extent to which major zones of vegetation—such as tundra conifer forest deciduous forest—were displaced beyond the ice border Work now being done in the arid and mountainous Southwest based on sediments in old lake basins shows clearly the downward migration of high altitude woodland and forest during glacial times and its subsequent replacement by semidesert or desert vegetation

The accompanying table although much simplified and omitting certain interesting fluctuations of the past 2000 years illustrates the general character of postglaciation change *See* PALEOBOTANY PLANT GEOGRAPHY VEGETATION ZONES [P B S]

Bibliography E L Braun *Deciduous Forests of Eastern North America* 1950 Pierre Dansereau *Biogeography* 1957 H Godwin *The History of the British Flora* 1956 P B Sears Xerothermic theory *Botan Rev* 8(10) 708–736 1942

Postulate

In a formal deductive system a proposition accepted without proof from which other propositions are deduced by the conventional methods of formal logic There is a certain arbitrariness as to which propositions are to be treated as postulates because when certain proved propositions are treated as postulates other propositions which were originally postulates often become proved propositions

The question of objective truth does not arise in connection with a postulate although the term postulate is sometimes *loosely used in connection* with tentative assumptions with regard to matters of fact In strict usage postulate is nearly equivalent to axiom although axiom is often loosely used to denote a truth supposed to be self evident *See* LOGIC [F W P]

Postglaciation phases in North America

Phase	Moisture	Temperature	Ice	New England	Southern Ohio	Northern Ohio	Alaska
8	−	W	R				Tundra-spruce
7	+	W ±	A	Hemlock-chestnut	Beech maple	Beech maple	(Climax ti n)
6	−	W +	R	Oak hickory	Oak hickory	Oak hickory	Spruce
	+	W ±	A	Oak hemlock	Beech hemlock	Beech hemlock	−
4	−	?	R	Pine	Pine	Pine	−
3	+	C	A	Spruce	Spruce	Spruce	−
2	−	C	R	Tundra	Pine	(Glaciation)	−
1	+	C	A	(Glaciation)	Spruce	−	−

Symbols Phase numbers unofficial for convenience only Moisture signs (+) moist phase (−) dry phase Temperature C—cold W—warm Ice A—advance R—retreat

Posture regulation of

T ntra tion of mu cl erve not only t move the j t in loc motio b t al u to maintain the p ts in fi d po it during the a umption f st t ary attitud p tures (se MOTOR SYS TEMS) A impl mple of the le of the neuro m lar sy tem i maintaining p t re i een h a man m t s a stand g p t When the body s i th p ght p t o g a itational f est d t cau e the j t to fle a d tl e limbs t ll p e u d the weight f the lody Th is pre nted b the t act on of the exten or mus les of the l l mb th t g a itational force ar c unt cted d the up ght po ition m main tained The m scula tract n eq ired fo erect standing i m t ed by eflex a t d r q e m e s eff rt o att t i terr pt f th erves upplyin the l m cles de troys not only th abil ty to alk but l o th bility to tand (REFLEX, UNCONDITIONED) Th r flex mecha n m r ural tin po tu ar h ghly fle bl that p e a ti cha ges i position f th bod a se a t m c ha ge in the pattern of l tr ct n wh h e ult in ta ce at t dy app pri t to the new m cha ging orienta tio f body The efle m diat g these re ti are kn wn a p tu l efl e

Decerebrate rigidity The p al r flex mecha m resp ble f ta ding may be st d ed in intact an mals b t i b t ee n decereb ate p parat a m l n whi h the brain tem ha been ompl tely t a ct d between the super r and inf r r ll ul t produ e total i ol t on of th l wer b a t m med lla nd pinal o d from th r stral (te r) b st uct es The cat surv es ch d cal su ge y surp isingly well desp te the oc ur e e of c ta n neurol gical d fi cits, the tal f ncti n f re pir tio and c cula tion ad quately maint ined by the remain g sol ed n l t uctu es A triking feature f the dece eb ate prepa at o s n e agge ted posture first de ib d by C S Sh i gto 1898 T e limbs um p sitt n f rig d te n a d ...ly es et p e fle n of the jo ts O ce k lbl fl ed th jo nts a e ea ly xte ded P lp t f th mu l rev al that th g d ty is m ta ed b a ti e c ntr ct o f the e t or e les f the l mb

E tenso rig d ty fi nt t pp t the weight f th bod a d whe the m l i pla ed on it feet, t ta d g dly f t l ghtly pp rted from th d t p nt t ppl g M le ther than th se f th l mb e sim la ly ff cted the head h ld t w th th h n up the j w i ...ed t ghtl but d a t ly r ts ffo t to ... it, d the t l ft n t nd m ct Th m ... d play g rig d ty e the a t g ity m cle ... ppose th g a t t n l f m ted d g to ... ll p f th b dy De reb t in the ... m l h h re t g ty w th its fle or mu cle as it ha g up d d wn from branches causes a fle or r g d ty

Decerebrate rig d ty i th a ca icature of tanding The e g t n i due to the r lease f spinal motone r f m hibit ry imp l e wh ch originate i p e mental truct re d nor mally des nd th gh tho e p thw y which have been i ter pt d by the brai t m t an e tio The role f th e supr e me tal i ucture is d cussed below Decerebrate rigid ty is a reflex th t require egm nt l afferent i p t to mai tai the discharge of th motone ro pplying the af fected ant g ty m cles Wh the dorsal pinal ro ts conveyi ry impt l f m a rig d l mb to the pinal rd di ided d ty d appears d the limb b m fl c id S milarly v tral r t ect n ab l h gidity by te rupti g the effe e t p t f the r fl e

The g n f the ff e t imp l which m in tain dece b t igidit i n t in receptors of sk f joi t f te d ns bec e it p s ts un li ted after rem l f ski nd fter l l ane th t wh ch re d ecept e s t e are injected t j i ts d t d n The re p il le e eptors a e n the m l them l e a d the adeq te stimul f the r t t n i t etch f the m l be u e they thu g ter ents c r g in th b dy it If th y are l ed s pro pri ept as pp d t e t ept (for exam ple eti l d t ctil pto) wh ch eact to ext l e e t Th imp l g ated in the stretch m pt s f a t a ity m cle by gra ita t l f es (wh h tend t u the limb to flex and th t t h th t or m scl) ar tra m tt d t the p l rd aff t fib s f the dorsal ro t The st t h se t m ffe e t m ke di e t nect w th th moto e o supplying the stretched m cle a d itiat n them a efferent d sch ge whi h l t m cula contr ct n op p ng elong t n of the mu cle d th s maintains upright p tu e F rthe th effer t d ch rge m grad d so th t efle m cula co tra tion is th gh de abl ge f tr tch g fore s ficie t t m t the m le t fi ed le gth d th t p eve t ll p e f the l mb

For mple u b rd d t nd only the we ght f the b dy t d t b kle the k e s a d tr t h the k t n s Th mild d re f st t h x t ly th t et h pt f l we t th h d the ept d ch g at rela t lv l w t C q e tl th ked fle nt d h ge a d th lta t fl l t o i pr ly ffi t t keep th j t tr ght If ly l d pl ed p th h ld the dd t l t t h f t tr tch r cep tor t d ha g mp l es t h h at and al o el ct d ll g n th e h gh th e l ld rec p t wh h we p e ly le t (e t tm nt) The d aff e t d h rg a t t m e mot r dd th m t h gh r te th t the re lt t fl x t ti i i d uffi tly t ff t the wly mp d bi d The

stretch or myotatic reflex as it is called provides an automatically regulated mechanism for upright posture which functions effectively regardless of varying demands placed on the limb musculature

The stretch reflex is responsible for muscle tone that is the resistance of the muscle to passive elongation When the stretch reflex is absent the muscle is hypotonic or flaccid when stretch reflexes are exaggerated as in decerebrate preparations the muscles are hypertonic or spastic

A quantitative estimate of the sensitivity and effectiveness of the stretch reflex can be obtained from experiments employing the fall table of Sherrington the important feature of which is a movable top which can be lowered for measured distances The leg of an experimental animal is fixed rigidly to a stand on the table and a muscle is dissected free and attached to a tension recording device mounted on a stand independent of the movable table top When the table top is lowered the muscle is stretched and the tension developed in the muscle recorded Part of the tension is caused by the elasticity of the muscle this moiety can be determined by denervating the muscle and repeating the stretch The difference in tension developed in the innervated and denervated muscle gives a measure of the tension caused by active reflex contraction In the quadriceps (knee extensor) muscle of the cat a stretch of 8 0 mm gives rise to an active reflex tension of 3–3 5 kg

Stretch receptor and its control The sense organ of muscle which mediates the myotatic reflex is the muscle spindle This organ consists of six or seven small specialized muscle fibers called intrafusal fibers They are enclosed in a connective tissue capsule the ends of which attach to the tendon or to the connective tissue surrounding the ordinary muscle fibers (extrafusal fibers) Afferent nerve fibers penetrate the capsule and terminate in a helical arrangement (annulospiral ending) or a bushy ending (flower spray ending) on the equatorial region of the intrafusal fibers The equatorial region of the intrafusal fibers is noncontractile but the two ends or poles of the fibers are contractile and receive motor innervation from small diameter efferent fibers which penetrate the capsule along with the sensory fibers The spindles which lie in parallel with the extrafusal fibers are subjected to stretch when the muscle is elongated and the resultant distortion of the nerve endings excites them to discharge impulses However if the extrafusal fibers contract and the muscle is allowed to shorten the intrafusal fibers become slack and the endings cease firing The slack can be taken up if the small motor fibers supplying the contractile poles of the intrafusal muscle fibers are activated The small motor fibers (3–6 μ in diameter) are histologically and functionally distinct from the large motor fibers (9–13 μ in diameter) which innervate the extrafusal fibers The former which comprise about 30% of the fibers in the ventral root of the spinal cord are devoted exclusively to the innervation of intrafusal fibers and are therefore called fusimotor fibers Fusimotor excitation develops no measurable tension in the muscle because the contractile tension of the small intrafusal fiber is negligible compared to that of the extrafusal fibers Instead the function of the fusimotor fibers appears to be that of a sensitivity control for the spindles When fusimotor activity is great the spindles are kept taut and slight muscle stretches elicit a high rate of afferent discharge In the absence of fusimotor activity the spindles are slack and greater muscle stretches are required to establish a comparable discharge The stretch reflex mechanism therefore includes a loop from muscle spindle to motoneuron causing extrafusal contraction and spindle silence and one from sense organ to fusimotoneurons The afferent paths which drive the fusimotoneurons are not entirely understood Part of the drive is through segmental pathways noxious stimulation of the skin is particularly effective in increasing fusimotor discharge and secondarily increasing the spindle afferent discharge to stretch Certain descending paths from suprasegmental structures also exert a marked influence on fusimotoneurons

Regulation of the stretch reflex In the decerebrate preparation the stretch reflex is abnormally sensitive with the result that slight stretches induce inordinately large efferent discharges This hypersensitivity is ascribed to the interruption by the intercollicular section of pathways originating rostral (anterior) to the section and exerting directly or indirectly an inhibitory influence on the segmental stretch reflex mechanism The origin of those pathways is not entirely clear In man and higher primates spasticity a syndrome similar to decerebrate rigidity follows lesions of the rostral precentral cortex Probably the inhibitory system originate from several supracollicular structures

Removal of an inhibitory system alone will not cause exaggerated reflex response any more than removing the brakes from a stalled car will make it go The question of what drives the motoneuron released from supracollicular inhibition is considered next The segmental afferents from the stretch receptors provide part of the drive but suprasegmental structures also contribute because spinal transection abolishes decerebrate rigidity as readily as dorsal root section Between the spinal cord and the colliculi there must be a group of neurons or a center which facilitate the segmental stretch reflex arc Experiments indicate that facilitatory impulses originate in the medulla and reach the spinal level partly by way of the reticulospinal tract and partly by the reticulospinal path At the spinal level these impulses sensitize the stretch reflex by converging with segmental afferent from stretch receptors on motoneurons and by driving the fusimotoneurons thus increasing the sensitivity of the spindles to stretch and augmenting the segmental afferent input to the motoneuron

Lengthening reaction When the limb of a decerebrate cat is forcibly flexed resistance develops and increases throughout the initial part of the

led g but t some point uddenly d appears so t the m cl el g t s e d ly Th lengthe i g re tr n r fl x n o i n The ceptor is the Golgi t d n rgan nd it di charge cause n hibit n f the m t neuro s of the tretched mu d Compl t inh bit on occurs nly with tron stret hes bec u the G lg te don o g ns ha e higher thre hold tha m cle p ndle end n The length n g react n p otects the mu cle aga n t l d pr ent g th de elopment of inju i us te ns the ce e tretch

Tonic neck reflexes The egm ntal stretch reflex pr de f r upr ht p ture but a a iety of se re p ts alte s its t r otyp d pattern and perm ts a fle ible ri ty of po t re or attitudes Th th h ad of the d c reb ate t s bent fo ard n the he t th f l mbs flex a d i d ty n ases m the hi dlimb The r ult ng attit de th t l a at lo king nde a bed Con r ely d fl xion f the head i re e f rel mb r g d ty and ca ses flexion f the h ndlimbs th s is the p t l patte n f a c t look ng p t th top of a bed s d r dy t p in The r ept rs m d atin these att t d al refl x re p pr ocept rs in th t of the neck

The rot t of th he d a nd th l ng a th k lie ts an th r po tural change exten t ne inc e e in the l mb both f e d hind, to d bich the ch n s t rn d O th ppo te de exten o t ne d m n he Th mon bl r pt r a e aga n p op io ptors in n k j nt e tion f the erv cal d r al oot th h be th reflex p ttern

Ton c labyrinthine reflexes E en afte th t ic neck r flexes a e l m n t d by cervi l d s l ro t wit n cha ging th nimal pos ti n in space t ren th t n t n l the l mt Ext o t ne s r t l n ll f l mbs whe th animal is bn nt fly s pine w th the nout at a angl f above the h r t l pla e R tat o of the an l ar d the h z ntal x prog ely re ette t t e a m n m m be ng e hed h p n po t o with th n ut t lted 45 below th ho z tal pl n The e p bl n pt the ad h gan of th laby inth of the e the ofter fi r ti n a e tat c nd d n t d pend p ler t n of th he d S EAP

Righting reflexes Wh n d opp d th ough pa e a d gl ed f m th up i ht p t n th inta t t rap dly reo ent ts bod so that t l d n ts l ty i lo t t the decer b te c t wh h l ben fald p ght Right ng i t d pend nt up n al c h u e t n bl d d n m ls lter ompl te t th eb al cort R fl x ght g L ted by the foll i g mechani m L n th efl D t tat n of th h ad de ted b th t l th e ept r of the lab i th head a m h tal pos ti Th fle t a refl x th t t doe n t depend p n n l th h d

Body r ghting reflex s Wh n a bl nd d laby r nthe tomiz d nimal is pl ced on ts ide the head ti rns a d a sum the h r zontal po iti n The refle i n tiated by th symmetr stimulation f the body u fa e by the weight f the b dy

Ne k r ht ng fle s When the head ha be n ri hted by the lab nth ne and body righting re flexes the resultant twistin f the neck ex te proprioc ptors whi h reflexi ly ffe t trunk and l mb mu cul ture o th t the body as um s a ho i zontal p tion

Body eflex s a t ng on body A ymm t i st mu lation of the body su f ce i a anim l lyi g on e s de cau e the body m right t elf e en when the head is held in the lateral po iti n

I s al ighti g efl xes In the ab enc f all the f re ng r fle me hani m i ual timul cau ghting of the he d and b dy Optic l r sual rightin s d pe de t on the c r b al cort x

Placing and hopping reactions The e a p s t r l reflexes which l k th i ual ighti re flexe d pe d upon th nteg ity f the ce ebral c rtex Plac n a t on ensure that the f et a placed under th b dy i the proper po ition f r t nd ng they may b i ual r nonvisual When an animal lowered by hand t ward s bl sup p the l mbs eek th upport If a bl ndfolded animal im larly l w ed ntact of the fe t with the ppo t s ffic ent to x ite tactile end ngs o mu l p op io epto s i itiate non i ual plac ng f th fe t H pp n eacti n re elic ted when the b dy is d pla ed h r z ntally with the f et tra l ng on the fl r the f et ex ute a s r e of hops so that the legs r ma n a supp rt ng p t on erti al to th b dy H pp ng rea tio s are both su l d on sual i th latte t ce mu cle pro p i epto s t t th refl

Labyrinthine acceleratory reflexes The role of labyr thi e eceptor tat post al r fl xe ha l e d b e d ribed The ad q iat t mulu f ther labyr nth n refl xe eithe n ti n no elo ity f displ c me t but rather accele t on of th he d It was once th u ht that the ma ul e of the t l nd ule of th inner ear w e spo bl f the static efle whe s the c i tae of th s m r ula can l w the recep ti e me h m nde ly ng the a el rat ry re flexes Rec nt d n ugg st that th d ch tomy i n t th s ha p nd that b th ut icl and sem c r l r an ls o ta r ptor m d t g b th t t d a c l t v e p

The mpl t c el at y refl x is l ited by l n a c elerat on a f e ample udden low r ing h d d wn of bl ndf lded a imal au the f r l mbs to e te d and the t t sp d Thi e p e which s la l g i th laby inth t m d m l pp rt the an mal n l d ng fr m a j mp An l ele at els it labyr th fl x alt r t f the mu l t of ne k limb tr k d y The re p n f the ve lled ny t gmu As the he d t te th yes swing l wly th pp t di e t n (l w ph e) to m t fi ti n f th gaz u t l e h g a

stretch or myotatic reflex as it is called provides an automatically regulated mechanism for upright posture which functions effectively regardless of varying demands placed on the limb musculature

The stretch reflex is responsible for muscle tone that is the resistance *of the muscle to passive* elongation When the stretch reflex is absent the muscle is hypotonic or flaccid when stretch reflexes are exaggerated as in decerebrate preparations the muscles are hypertonic or spastic

A quantitative estimate of the sensitivity and effectiveness of the stretch reflex can be obtained from experiments employing the fall table of Sherrington the important feature of which is a movable top which can be lowered for measured distances The leg of an experimental animal is fixed rigidly to a stand on the table and a muscle is dissected free and attached to a tension recording device mounted on a stand independent of the movable table top When the table top is lowered the muscle is stretched and the tension developed in the muscle recorded Part of the tension is caused by the elasticity of the muscle this moiety can be determined by denervating the muscle and repeating the stretch The difference in tension developed in the *innervated and denervated muscle gives a measure* of the tension caused by active reflex contraction In the quadriceps (knee extensor) muscle of the cat a stretch of 8 0 mm gives rise to an active reflex tension of 3–3 5 kg

Stretch receptor and its control The sense organ of muscle which mediates the myotatic reflex is the muscle spindle This organ consists of six or seven small specialized muscle fibers called intrafusal fibers They are enclosed in a connective tissue capsule the ends of which attach to the tendon or to the connective tissue surrounding the ordinary muscle fibers (extrafusal fibers) Afferent nerve fibers penetrate the capsule and terminate in a helical arrangement (annulospiral ending) or a bushy ending (flower spray ending) on the equatorial region of the intrafusal fibers The equatorial region of the intrafusal fibers is noncontractile but the two ends or poles of the fibers are contractile and receive motor innervation from small diameter efferent fibers which penetrate the capsule along with the sensory fibers The spindles which lie in parallel with the extrafusal fibers are subjected to stretch *when the muscle is elongated* and the resultant distortion of the nerve endings excites them to discharge impulse However if the extrafusal fibers contract and the muscle is allowed to shorten the intrafusal fibers become slack and the endings cease firing The slack can be taken up if the small motor fiber supplying *the contractile* poles of the intrafusal muscle fibers are activated These small motor fibers (3–6 μ in diameter) are histologically and functionally distinct from the large motor fibers (9–13 μ in diameter) which innervate the extrafusal fiber The former which comprise about 30% of the fibers in the ventral root of the spinal cord are devoted exclusively to the innervation of intrafusal fibers and are therefore called fusimotor fibers Fusimotor excitation develops no measurable tension in the muscle because the contractile tension of the small intrafusal fibers is negligible compared to that of the extrafusal fibers Instead the function of the fusimotor *fibers appears to be that of a sensitivity control for* the spindles When fusimotor activity is great the spindles are kept taut and slight muscle stretches elicit a high rate of *afferent discharge In the absence* of fusimotor activity the spindle are slack and greater muscle stretches are required to establish a comparable discharge The stretch reflex mechanism therefore includes a loop from muscle spindle to motoneuron causing extrafusal contraction and spindle silence and one from sense organ to fusimotoneurons The afferent paths which drive the fusimotoneurons are not entirely understood Part of the drive is through segmental pathways noxious stimulation of the skin is particularly effective in increasing fusimotor discharge and secondarily increasing the spindle afferent discharge to stretch Certain descending paths from suprasegmental structures also exert a marked influence on fusimotoneurons

Regulation of the stretch reflex In the decere*brate preparation the stretch reflex is abnormally* sensitive with the result that slight stretches induce inordinately large efferent discharge This hypersensitivity is ascribed to the interruption by the intercollicular section of pathway originating rostral (anterior) to the section and exerting directly or indirectly an inhibitory influence on the segmental stretch reflex mechanism The origin of those pathways is not entirely clear In man and higher primates spasticity a syndrome similar to decerebrate rigidity follows lesions of the rostral precentral cortex Probably the inhibitory system originate from several supracollicular structures

Removal of an inhibitory system alone will not cause exaggerated reflex response any more than removing the brakes from a stalled car will make it go The question of what drives the motoneuron released from supracollicular inhibition is considered next The segmental afferents from the stretch receptors provide part of the drive but suprasegmental structures also contribute because spinal transection abolishes decerebrate rigidity as readily as dorsal root section Between the spinal cord and *the colliculi there must be a group of* neurons or a center which facilitate the segmental stretch reflex arc Experiments indicate that facilitatory impulses originate in the medulla and reach the spinal level partly by way of the vestibulospinal tract and partly by the reticulospinal path At the *spinal level these impulses sensitize the stretch* reflex by converging with segmental afferent from stretch receptors on motoneuron and by driving the fusimotoneuron thus increasing the sensitivity of the spindle to stretch and augmenting the segmental afferent input to the motoneuron

Lengthening reaction *When the limb of a de*cerebrate cat is forcibly flexed resistance develops and increases throughout the *initial* part of the

Physical propert of potas i m m t l

Property	T mper t re C	F	M tr (scie t f c) un ts	B iti h (e m eer) un ts
Dens ty	100	1	0 819 g/ m	51 1 lb/ft
	400	[illegible]	0 747 g/cm	46 7 lb/ft
	700	1 9	0 6 6 g/cm	4 lb/ft
Melting point	63 7	147		
Boiling po t	60	1400		
Heat of fus	63 7	147	14 6 cal/g	6 3 Bt /lt
H t of por t	63 7	1400	496 c l/g	893 Btu/lb
Viscosity	70	158	5 15 m ll po se	6 5 k tic u t
	400		2 58 m ll po ses	3 5 k tic un ts
	800	147	1 36 m llipo es	k t i n ts
V por pressure	34	618	1 mm	0 019 lb/in
	696	1 85	400 mm	7 7 lb/in
Thermal co d cti ity	00	[illegible]	0 017 l/(sec)(cm)(cm)(C)	6 0 Bt /(l)(ft)(F)
	400	7	0 09 cal/(sec)(cm)(m)(C)	1 Bt /(h r)(ft)(F)
H t cap ty	00	39	0 19 cal/(g)(C)	0 19 Bt /(lb)(F)
	800	147	0 19 l/(g)(C)	0 19 Bt /(lb)(F)
Electrical resi t ty	150	30	18 7 m crohm-cm	
	300	57	8 m rohm-cm	
Surface tens	100-1 0		Abo t 80 dynes/cm	

Chemical properties P tassi m is e en mo react th sod um It re t r u ly w th the oxygen in a to fo m th monox de K_2O nd the p d KO f th pre nce f e ess o yge it readil f rms th sup x de KO (f me ly bel ed to b K_2O)

Pota m does t re ct w th nitrogen t f rm a nitrid e e at ele ated t mperat W th hy d g pota m ct slowly t 200 C a d n dl t 350-400 C. It form the least stabl h drid f ll th alkali metals

The re t bet een p t s um a d wate o s lent, e n at t mpe t es a l w as −100 C The h d er l ed i s ally gn ted in reacti at room t mper t re R ct on w th aq e ac d are even m e v le t a d e ge n b g expl s

I t d f form g the h de w th ca bon po- ta m f rm a the i d finit s l d lut o with th pota um t m i te p sed b tw n the layer of th gr phit latt c

Pot m e t igo sly with the h l g n Like m d sod um r a t only s pe fici lly w th liq d b m n b t p t s m d t te i t t h n P t m gn tes the acti n w th lso

The re t n f pot m with ammo g p m d KNH d hyd g P t m f m d m in th t a pl c rb yl bon-l hen pot im r t d e tly w th arb n a d

Pota m r ct th m g n comp und but not th tu ted al ph t c hyd rb Each r m t hyd c rbo m t l tion g rgan p t ium mp ind W th len p t [illegible] tyl d r f rm d th d gen M t re t n of p t um w th th r mpo ds a e y m l to th e m. In th f m f N K alloy pot m i my effect t ly t f th t a st fi at

ction in l ed the comme l m d fi t n f l d

Availability Pot s m metal is ava l ble n ne grade of 99+% p rity w th sod m th maj mpu ty The a nual p d tion i abo t 50 000 lb/year Th p f the metal r es w dely with the qu t ty rde ed 1 5 lb l t t $4 75 pe lb i 19 8 and 100 000–300 000-lb lots co t $1 00 p lb P t ium salts a [illegible] e lly mo expensi than the p d n d um salts P t s m hyd de a d pot s um b te ll fo abo t 9¢ pe lb (f 1958) compared to 2 3¢ per lb f the r espo d g d um mp ds

Handling Handling of p tas um metal i much the s me th t f d m metal w th two maj ept ns First the f m ti n f the supe x de KO diffi lties bec se t can rea t igor usly w th hyd b a d othe g nic matte Se nd p t s m [illegible] er lly m acti tha d um Potass um f rms a plosi c b yl w th bon mo ide nd the metal detonat s n [illegible] t w th bromi e

G lly d m p tas i m a d the d m p t s m (NaK) all ys are s dered t b th s me g eral cla s of r t ity ll wi g for th l m l d ff es tl ed ab and f r th l q d (d he a mo e t e) nat e f th N K lloy er w d omp ition ng S Sodium

Principal compounds P t s m hlo de KCl th m t mp tant p t um mpo d It t o l th f m wl h pot um ft fo d t b t t s the f m wh h p t h i d f i l e

P t um hyd d KOH l k wn t pot h It lly m de by th l t l f q s l t f p t i m chl ride

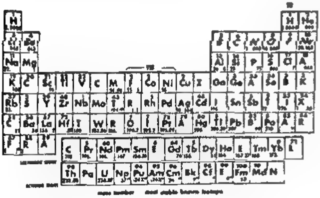
P t um b t K_2CO_3 m d f m po- t i m h d de d b d x d It n t b m d b th S l y p us d for d m

maximum deviation they swing rapidly back in the direction of rotation to the forward looking position (quick phase) the process repeated over and over causes an oscillation of the eyes When the head reaches constant velocity ny ta mus disappears only to reappear when rotation cea es in the latter instance however the quick phase is in the direction opposite to the original direction of rotation

Nystagmus may be horizontal vertical or rotatory depending upon the position of the head during angular acceleration When the head is bent forward 30 the horizontal emicircular canals are in the plane of rotation and the ny tagmus is horizontal When the head is flexed 90 onto the shoulder the vertical canals are in the plane of rotation and nystagmus is vertical With the head bent forward 120 or backward 60 rotation cau es rotatory ny tagmus *See* MUSCLE MUSCLE (BIOPHYSICS) NERVOUS SYSTEM PSYCHOLOGY PHYSIOLOGICAL AND EXPERIMENTAL [H D P T C R]

Potassium

With an atomic number of 19 and an atomic weight of 39 1 potassium K stands in the middle of the alkali metal family below odium and above rubidium in group Ia of the periodic table of the elements It is a lightweight soft low melting reactive metal In 1807 Sir Humphry Davy i olated metallic potassium by electrolysis for the first time It is very similar to sodium in its behavior in metallic form and its u es are limited as a consequence of the availability of low cost sodium in large volume



Uses Potassium chloride finds its main u e in fertilizer mixtures It al o erves a the raw material for the manufacture of other pota sium c m pounds

Potassium hydroxide is u ed in the manufacture of liquid oaps and pota sium carl onate in making soft soaps Pota sium carbonate i also an important raw material for the gla s industry

Potassium nitrate is u ed in matche in pyrotechnics and in imilar items which require an oxidizing agent

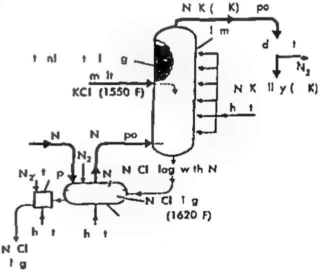
Occurrence Pota ium is a very abundant element ranking eventh among all the elements in the earth s cru t 2 59% of which is pota ium in combined form Only oxygen ilicon aluminum iron calcium and sodium are more abunda Sea water contains 380 parts per million maki potassium the sixth mo t plentiful element in o tion being exceeded only by chlorine odiu magnesium sulfur and calcium

Pota sium compounds are found in the hi torically important deposits at Sta furt in German which consi t of sylvite (KCl) and carnalli ($MgCl_2$ KCl) In the United States exten ive p tassium depo its containing sylvite and polyhali (2CaSO K SO_4 2H O) are located at Searle Lak California and Carl bad New Mexico In add tion pota h salts are found in France Spain P land the Soviet Union and in the Dead Sea

Metallurgical extraction Commercial pota iu chloride is melted in a gas fired melt pot and is fe to the exchange column (ee illu tration) in th commercial manufacture of pota sium metal b thermochemical means The molten potas iu chloride flows down over steel Ra chig rings in th packed column It is met by a cending odiu vapors coming from a gas fired reboiler A equilibrium is et up between the t o givin odium chloride and pota sium metal as the prod ucts The sodium chloride formed i continuou l withdrawn at the ba e of the apparatus The colum operating conditions may l e varied to give prac tically pure pota ium metal as an overhead prod uct or to vaporize odium along with the pota iu to give odium potassium (NaK) alloys of varyin compositions as products Pota sium metal of o e 99 5% purity can be produced continuou ly

Unlike lithium and odium which are produce by electrolysis pota sium reacts with carbon elec trodes and al o can form an explo ive carbony in electrolysis (or in thermochemical method using arbon reduction) Therefore the thermo chemical route using the reaction l etween metallic sodium and potassium chloride ha pro en mo t practical and economic

Physical properties The phy ical propertie of potassium metal are ummarized in the tal le



P t m t acto

Physical properti of pota sium m tal

Property	T mperat re C	F	M t c (sc e tifc) n ts	Br t I (nginee ng) i n t
Density	100	1	0 819 g/cm	51 1 lI /ft
	400	75	0 717 g/cm	46 7 lI /ft
	700	1 9?	0 626 g/cm	4 lI /ft
M lt g po t	63 7	147		
Bo ling po t	60	1400		
Heat of fus	63 7	147	14 6 cal/g	26 3 Bt /lI
Heat f po at on	63 7	1400	496 c l/g	893 Bt /lI
Viscosity	70	1 8	5 15 m ll po ses	6 5 k t nit
	400	7	58 m ll po ses	3 5 k t un t
	800	147	1 36 m ll po ses	k t c ts
V por press re	34	648	1 mm	0 019 lI / n
	696	1 85	400 mm	7 7 lI /i
Therm l co d ct ty	00	39	0 017 al/(sec)(cm)(m)(C)	6 0 Bt /(h)(ft)(F)
	400	7	0 09 l/(sec)(m)(cm)(C)	1 7 Btu/(h r)(ft)(F)
Heat capa ty	00	39	0 19 l/(g)(C)	0 1 Bt /(lI)(F)
	800	147	0 19 c l/(g)(C)	0 19 Bt /(lI)(F)
Electric l res t ty	150	30	18 7 rohm-cm	
	300	572	8 m crohm-cm	
Surface te	100–150		Abo t 80 dy es/ m	

Chemical properties Pot s ium i even m e reactive th sod m. It react g r sly with the x g m a t f m the mon ide K O and the per de K O I the prese e f e ce s xygen t eadily f rm the p rox de KO₂ (forme ly bel eved to be K O)

P ta m does not react with nit gen to f rm a t d e n t ele ated t mpe atu With hy d gen p ta m re ct l wly at 200 C and ra dly at 3 0–400 C It f ms the l ast t ble hyd de t ll th lk li met l

The ct n b tween p ta i m a d w ter r e k l t e en at t mpe atu a l w a −100 C Th h d gen ol d ally ig t d r ct n at oom tempe tur Re t with qu s cid r ces m te lent nd erg on b ng pl i e l t d f f rm g th rbide w th c bo po ta m f rm a rath indefinite s l d s l tio with th p ta m at m terpo ed betwee the laye f th g ph te l tt ce

P t m r t vig ly w th th h l g Lith m d odi m eact ly supe fi ally w th h id b m e b t p t m d t t s in ont t ith it P t m g t th rea ti w th hd l n

Th re ct n of p t um with mm nia g es pe m m d KNH nd hyd g P t i m d n fr m d m n th t an expl i e a bonyl i f med hen p t m r a t d e tly w th c rbo mon id

Pot m r t th ma o g c mpou d b t t th t rated l ph ti hyd c bon X h som m l hyd oc bo m t l t n g g pota m c mp nd W th m p t m a tyl d ar f med P t m t w th l h l t f rm lk des l hyd gen M t tt f p t i m w th t yl mpo d a ry m l t th t m l th f rm f N K ll y pct m a q t t ly t f th t t f t re ction in l ed in the com ne cial mod ficat on of la d

Availability Pota ium metal is a ail ble i one g de (99+% pur ty w th odi m a the maj r mpurity The nual producti n is bout 50 000 lb/ye r The price of the met l va ies w dely with th q nt ty der d 1 5 lI l t c t $4 75 per ll 1958 and 100 000–300 000-lb l t cost $1 00 per lb P ta um salt a e generally mo e expensi e th n the rr p ding d m alt I ta s m hydr x de a d p ta ium carb nate ell for b ut 9¢ per lb (a of 1958) compared to 2 3¢ per lb f r the o re p nd g s d m c mp ds

Handling H ndl g f pot s um met l is much the s me a th t of dium metal with tw m j r e cept s F rst the f rm t of the uperoxide KO c es diff c ltie b ca e it can ct vigor usly with hyd oc b ns nd oth r organic matte Se d p ta m gen r lly m re reactive than od m P tas m form a expl e b yl w th arb m n de a d the metal deton te in nt t w th b mine

G e lly di m pota m nd the d m pot ium (N K) all ys are c d d t b n th am g al l of e t ty ll w ng f th l m al d ffe e ces outl d abo a d f r the l q d (nd hen m re re ct) tu of the N K all y e w de c mp t n r ge *See* SODIUM

Principal compounds P ta i m chlor d KCl the m t mp tant p ta i m c mp d It i t ly the f rm i wh l p ta m i fte f nd n t b t t i th f m wh l p t h is d fe til z

P t m hyd x d KOH l k w a t p ta h It i u u lly mad by th l c tr ly f q l t f p ta um chl de

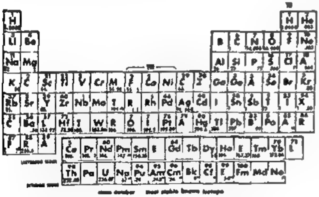
P ta m arb ate K CO mad f m po m hyd d d a bon d x d It n t be mad by th Sol ay p oces d f od um ca

maximum deviation they swing rapidly back in the direction of rotation to the forward looking position (quick phase) the process repeated over and over causes an oscillation of the eyes When the *head reaches constant velocity* nystagmus disappears only to reappear when rotation ceases in the latter instance however the quick phase is in the direction opposite to the original direction of rotation

Nystagmus may be horizontal vertical or rotatory depending upon the position of the head *during angular acceleration When the head is bent* forward 30 the horizontal semicircular canals are in the plane of rotation and the nystagmus is horizontal When the head is flexed 90 onto the shoulder the vertical canals are in the plane of rotation and nystagmus is vertical With the head bent forward 120 or backward 60 rotation causes *rotatory nystagmus* *See* MUSCLE MUSCLE (BIOPHYSICS) NERVOUS SYSTEM PSYCHOLOGY PHYSIOLOGICAL AND EXPERIMENTAL [H D P T C R]

Potassium

With an atomic number of 19 and an atomic weight of 39 1 potassium K stands in the middle of the alkali metal family below sodium and above rubidium in group Ia of the periodic table of the elements It is a lightweight soft low melting reactive metal In 1807 Sir Humphry Davy isolated metallic potassium by electrolysis for the first time It is very similar to sodium in its behavior in metallic form and its uses are limited as a consequence of the availability of low cost sodium in large volume



Uses Potassium chloride finds its main use in fertilizer mixture It also serves as the raw material for the manufacture of other potassium compounds

Potassium hydroxide is used in the manufacture of liquid soaps and potassium carbonate in making soft soaps Potassium carbonate is also an important raw material for the glass industry

Potassium nitrate is used in matches in pyrotechnics and in similar items which require an oxidizing agent

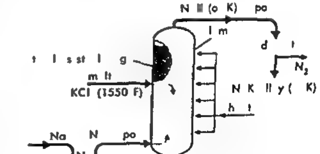
Occurrence Potassium is a very abundant element ranking seventh among all the elements in the earth s crust 2 59% of which is potassium in combined form Only *oxygen* silicon aluminum iron calcium and sodium are more abundant Sea water contains 380 parts per million making potassium the sixth most plentiful element in solution being exceeded only by chlorine sodium magnesium sulfur and calcium

Potassium compounds are found in the historically important deposits at Stassfurt in Germany which consist of sylvite (KCl) and carnallite (MgCl KCl) In the United States extensive potassium deposits containing sylvite and polyhalite ($2CaSO_4$ K SO_4 2H O) are located at Searles Lake *California and Carlsbad New Mexico In addition* potash salts are found in France Spain Poland the Soviet Union and in the Dead Sea

Metallurgical extraction Commercial potassium chloride is melted in a gas fired melt pot and is fed to the exchange column (see illustration) in the commercial manufacture of potassium metal by *thermochemical means The molten potassium* chloride flows down over steel Raschig rings in the packed column It is met by ascending sodium vapors coming from a gas fired reboiler An equilibrium is set up between the two giving sodium chloride and potassium metal as the products The sodium chloride formed is continuously withdrawn at the base of the apparatus The column operating conditions may be varied to give practically pure potassium metal as an overhead product or to vaporize sodium along with the potassium to give sodium potassium (NaK) alloys of varying compositions as products Potassium metal of over 99 5% purity can be produced continuously

Unlike lithium and sodium which are produced by electrolysis potassium reacts with carbon electrodes and also can form an explosive carbonyl in electrolysis (or in thermochemical methods using carbon reduction) Therefore the thermochemical route using the reaction between metallic sodium and potassium chloride has proven most practical and economic

Physical properties *The physical properties* of potassium metal are summarized in the table



P t m e t act

Fig 2. Irish p t t pl t h w g f t (USDA)

t be o th 2 n m m m d m te e p o d ed w th 2 m th f m date f pl nt g i arly an t w th 4–5 m nth l te a tes.

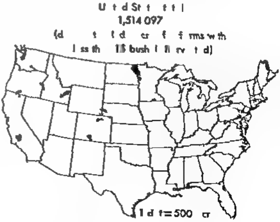
Varieties S nce th g z t n n 1929 of the N t l P tato B d g P o m m y ew arieties h e b n d t b ted d s m f the r d pl g th old r New r t a res tant to t o r mo d r h gh y eld ng and a g lly f g d m k t d ki g q l ty Th 19 7 U t d St t e tifi d s d p t p od ti r p rt l t 13 ld a et n trod ed bet een 1850 d 1900 nd 41 new s r le sed n 1932. Th K t hd n a ety l ed n 1932, n w the m t w d ly gr wn l t ety F ll g Kat hd n d f ed p t t p d ct Ru et B b nk R d Po t Cobbler Ke be Wh t R e Ch ppew R d LaSota, Ch kee S b g Red M Clu e Tr mph Green M u t and R t R r l Th a t e ted 93% f that ye c rt fi d d p t es (tube c t int t a d u d f r pr d ction)

Th p t t s prod ed mme ally n rly e t t th c ent ated p d ct i p rt (N or Id h Cal f rm N w Y k Min t N rth D k ta, d Col d (F g 3) S 1948 the annual pr d t n m the U t d St tes h ed f m 327 000 000 to 432 000 000 bu (196 000 000–259 000 000 cwt) D r the am pe od th t t l an l f m val e h s ed fr m bout $300 000 000 $685 000 000

Chemical composition The chemi l mposi ti n f the Ir h potato s g eatly by ar ty grow cond t n ncl d ng climate soil a d fert l t on a d the temp ature d le th of t m in t age P t toes nt i 75 85% water 12–18% t ch b t 2% p tein 1% in rganic mpound bout 0 5% su (fre hly harv ted t be) 0 5% o ga cid (mai ly citri) and 0 4% de fib The I sh p t to i good rce f itam n C I lb of b led n wly h rve ted pota t s cont s th m m m daily dult r quir ment f th s t m H wever th vit m n C nte t de c e w th to a sp lly t tempe at es b low 50 F

Use A ual nsumpt n f pot toes n w ab t 100 lb p pita A d wnwa d t e d n n mpt f u p ce d pot toe eem t ha be t pped dur th l te 1950 m ly be u f ed f po ed p od t uch s p t t ch p f n p t to p od ts ps d dehyd ted m hed p t t Co umpti n of p e d p t t a d fr m 1 9 lb p r p t in 1940 t 23 4 lb n 1956 I 1956 45 000 000 bu w s sed p t to h p 10 t me th amo nt p par d a h ps n 1940 and 9 000 000 bu wa p ep ed fr F ch f i mp ed w th n n i 1940 P ce s d m d p tat es hi h n I d m tter f p t to h p nd f f n p e-par d pr d t I 1957 pp m tely 5 000 000 bu ws omm lly p pe l d s rv c t r t ts d th la u

St h m d f cull a d l wer g d p t t e by m n f tu g pl t M n a d Id ho a d n Lo Isl d i New Y k The m u t p d i t st h h a d f m l s th n 5 000 000 bu i 1951 i 28 000 000 b 1956 C ll and l w g ad p t t es e ls d fo l st k



Fg 3 I h p t t g th U t d St t f y (8 f th C)

bonate becau e potassium bicarbonate is too soluble in ammonium chloride solution

Potassium nitrate KNO_3 is made by fractional crystallization of an aqueous solution containing sodium nitrate and potassium chloride

Analytical methods As in the ca e of sodium the high water solubility of most potassium compounds complicates the analytical determination of potassium Qualitative detection is usually made by means of the violet potassium flame the sodium flame which is usually present as well is masked by viewing the flame through a cobalt glass filter

Gravimetric determination of potassium can be made using sodium triphenylboron sodium perchlorate or other reagents Rubidium and cesium interfere in most of the e gravimetric methods when they are present *See* ALKALI METALS [M SI]

Bibliography Am Chem Soc *Handling and Uses of the Alkali Metals* Advances in Chem Ser vol 19 1957 C B Jackson *Liquid Metals Handbook Sodium NaK Supplement* 3d ed 1955 R N Lyon (ed) *Liquid Metals Handbook* 2d ed Navexos P 733 (rev) 1954

Potato Irish

The white potato *Solanum tuberosum* of the plant order Tubiflorales grown in cool climates The Irish potato is the world s leading vegetable crop with an annual production of more than 8 000 000 000 bu and ranks with wheat and rice among the world s mo t important foods

Spaniards invading South America found the white potato under cultivation high in the Andes Mountains of Peru and Boli ia the region believed to be its center of origin and took it back to Spain in 1538 It was introduced into Ireland about 1586 History indicates that the potato was brought to Virginia from the West Indies about 1621 It was transported from Ireland by Scotch Irish immigrants to Londonderry (now called Derry) New Hampshire in 1719 and was given the name Irish potato *See* TUBIFLORALES

Characteristics This herbaceous annual has round or angular aerial green or pigmented stems which have axillary branches The stems vary from ¼ to 1¼ in in diameter and may grow erect to a height of 3–4 ft or they may be procumbent (creeping)

The leaves which are pinnately compound consist of a large terminal leaflet ubtended by three or four pairs of large petiolated leaflets borne laterally on a rachis the lea es are arranged pirally on the tem

Fibrous roots ari e on the underground stem in groups of three ju t above the nodes The roots grow about 24 in laterally and about 18 in deep under culti ation in humid region but the depth may reach 3 ft or more under drier conditi n

The flowers occur in cymo e inflore cence Each flower has a white pinki h or purpli h five lobed corolla and the anthers of the five tamens borne

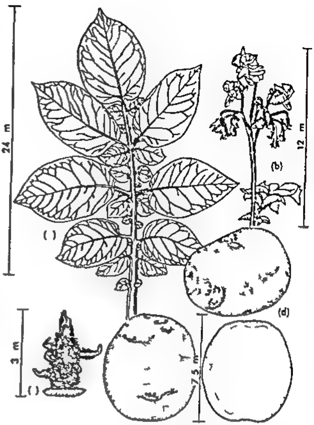


Fig 1 I sh potato (Katahd n va ety) ( ) P nately compou d leaf (b) Flowers (c) New pl t develop g from a t be sect on (seed p ece) (d) T bers show g eye co ta ning buds (*Dutch Potat All s H Vee ma a d Zo e Wage ge N the la ds*)

on the corolla tube are orange lemon or ome times greeni h yellow (Fig 1)

Under cool conditions arietie with fertile pollen may de elop fruit balls which are green berry like structures ¾–1½ in in diameter and contain numerous kidney shaped eed (Fig 2) The e are ometime mi taken for young t matoe Seed are u ed experimentally in the prod iction of new varieties De irable arietie h wever are propagated egetat ely l y mean of tuber ecti n which pos ess buds The e are often referred t a seed pieces

Tubers are formed on the tips of or are e ile on underground lateral tem r rhizome c mmonly called tolons The t ber i a h rtened thickened undergro ind tem ha ing node and internode the po iti n of the n de l e ng indicated by eyes which are leaf ar co taining lateral branche with axillary l d and very h rt internode Several pr uts may d el p fr m ne eye Depending on the ariety tuber vary in hap from round to ol l ng or o al in m tl ne f kin in depth of eye and in kin c l r fr m light yellowi h l rown t red Varietie al o iff in tim of maturity in re i tance t li ea and in e t in adaptation to different gr wi g con iti n a d in yield and marketal l quality f tul r in h l ing co king and pr ce g chara t r ti D pend ng on gr wing c diti n mark t l l ed

Fg 1 S eet p t t ( ) P rt R y m v ty b I g w J rsey typ (USDA)

th ts b i b k down i t s mple s a s (glu cose and fruct e) nd n s t med at pr du t d tra. Th s gi it a m t sy upy n t n y m h ts eet tha that f the drv (Je ey) type On cook g th g r i the d y type ma ns s
sort se

Th y m pr d c d l rg ly i th uthern h ever be e f the breedi f m e d d pt d ettie t is w be g gr wn h rth The Jer y sweet p t t is g own l I ng th ea tern h f Vi g a Mary land Del w e d N w Je ey a d al o n Iowa and K s (F g 2)

Th t tal co mpt on f w t potat e in the U ed States, lik that f white p tat es r e a d ther high carbohydrat foods m now somewhat l wer th n i f rmer ye rs Neve theless the alue f the sweet potato ndustry in Lou a a is in reasi g at the rate f ab ut $500 000 of ma ket alue each year W th the de elopm nt of new a et e *the northern lim ts of sweet p tat pro* du ti n ha e been e te d d to Can da and no th e n Unit d St tes Th s ha e me ab ut by br edi g early a d better a iette In Michig n number of baby food m nufa tu e s are growing this crop f r pr ce i g

Breeding The principal bj ct es in sweet po tato br ed ng are h gher nutrit o l alues in clud ng h ghe itamin and m neral contents in r sed y eld greate d sease re ist ce and wider adapt ti n Lou iana Oklah ma G orgia N rth a d South Ca lina and mor re ently Cali fo n a hav i tigated b eed g programs The U S Departme t of Ag ultu e and e eral tates a e jo n ng n the t st g nd e aluat o of the newe seedling nd a et For x m pl e ch year i L uis na ab ut 20 000 se dl gs are g own and st d d Men f m all part of the wo ld e be ng trai ed in b ed g product o nd handling the c p The bette i t s a e nt t p ctic lly all the nt es f th t op al ubt p cal a d mo t of the tempe t zon s

Processing In the Un ted St tes th sweet po tato s c n d exte i ly in Lo s a and along the Ea te Sh re a d it pop la ty is creasing e h ye The fro en p oduct h als ppe ed on the ma k t The w t p tato h p an ther n w

Un ed S at 1 261 051
does not includ acreag f f rms with less than 20 bush l h rv ed

Fig 2 Swe po the year Burea f th C s U S D p tm t f Commerc g f th U d St t f

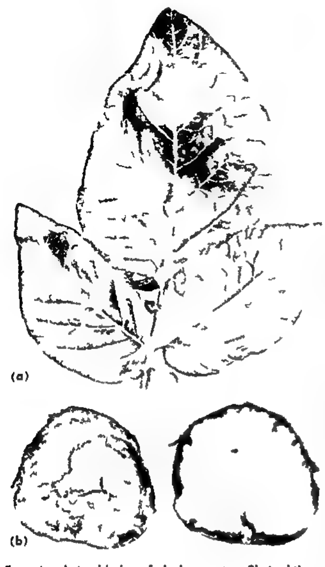


Fig. 4. Late blight of Irish potato (*Phytophthora infestans*). (a) Foliage infection. (b) Tuber infection. (USDA)

feed. *See* VEGETABLE GROWING; *see also* POTATO, SWEET. [A.H.]

Irish potato diseases. The potato is subject to numerous destructive diseases caused by fungi, bacteria, viruses, and nematodes. Potatoes may also be seriously injured by unfavorable growing or storage condition.

Fungus diseases. The most destructive single disease is late blight caused by the fungus *Phytophthora infestans*, which was introduced into Europe after the potato had become established as a major food crop (Fig. 4). A succession of epidemics starting about 1845 caused tremendous damage, especially in Ireland, where loss of the potato crop resulted in the starvation of 1,000,000 people and the emigration of 1,500,000 others. Late blight still causes important losses of potatoes in most of the important potato-growing areas and makes control programs necessary.

Less important fungus diseases of potato foliage are early blight and certain rusts and powdery mildew. Some fungi, especially *Rhizoctonia*, *Verticillium*, *Sclerotinia*, and *Fusarium*, attack the stem primarily, causing rots, canker, or wilts. Tubers in the field are subject to attack by many fungi which cause such diseases as black wart, powdery scab, common scab, silver scurf, leak, rhizoctonia disease, pink rot, and fusarium tuber rot.

Bacterial diseases. Similar bacteria cause black leg of the stem (*Erwinia atroseptica*) and bacterial soft rot of the tuber (*Erwinia carotovora*). The latter is extremely destructive in storage. Other destructive bacterial diseases are the ring and brown rots, both of which cause wilt or death of growing plants and rot or deterioration of tubers.

Virus diseases. As a group, viruses are probably the most important and insidious pathogens of the potato. Mild mosaic, rugose mosaic, leaf roll, latent mosaic, spindle tuber, calico, yellow dwarf, witches broom, haywire, and purple-top wilt are descriptive names of important virus diseases. Although most viruses do not kill the plant outright, they reduce the yield and quality of the tuber. Because most viruses are carried inside the tubers, the planting of certified disease-free tuber sections is the principal means of control.

Nematode diseases. Nematodes (small eelworms) cause root knot and golden nematode, tuber rot nematode, and meadow nematode diseases. Nematodes often persist in the soil for many years and, once established, they are difficult to control.

Mechanical injury. There also are many kinds of nonparasitic disease, such as blackheart, hollow heart, stem-end necrosis, and sprain. These injuries are caused by excessive heat or cold in the field or in storage, by nutritional disorder, by an excess or lack of water, and by poor ventilation in storage. *See* NEMATODA; PLANT DISEASE; PLANT VIRUS. [H.D.T.]

Potato, sweet

The fleshy root of the plant *Ipomoea batatas*. The sweet potato was mentioned as being grown in Virginia as early as 1648. In 1930 the selection of outstanding strains of the Porto Rico variety, which was introduced into Florida in 1908, was begun in Louisiana, and the best strain, Unit I Porto Rico, was released in 1934. In 1937 new techniques were developed for inducing the sweet potato to bloom and set seed. This stimulated a surge of research on breeding for higher yield, greater nutritional value, better shape, storage ability, market and canning quality, greater disease resistance, and new food products and industrial uses for the sweet potato throughout the southern states and from New Jersey to California. In 1957 the crop in the United States was valued at $71,427,000. In Louisiana, the leading commercial state for production of both the canned and fresh product, the annual value of the crop varies from $15,000,000 to $20,000,000, depending on seasonal conditions and demand.

Types. There are two principal types of sweet potato, the kind erroneously called yam and the Jersey type (Fig. 1). The chief difference between the two is that in cooking or baking the yam much of

functi of the coord tes i the elect ost tic field (ELECTROSTATICS)

Principle of superposition This state th t for m co fig n of charges the potential t a p t in n electr t t field i the algebraic m (th potent al th t ea h h ge alone would p o d ce at th p t. S e this call for lgebraic um (rather th n the tor um req r d for the alcul t of E) t often ea ier to set up the potent al fu t n for part ular phy cal p b-lem than t co tr ct d tly the fu t n f E. Then th th p tent l f n t known the d f ferential el ti h p $E = -\text{grad } V$ the o e to f f l t (E the th n th ntegr l re l n h p of Eq (1) If V s e pre ed i Cart n con d t th grad t eq atr i

$$E = -\left(i\frac{\partial V}{\partial x} + j\frac{\partial V}{\partial y} + k\frac{\partial V}{\partial}\right) \qquad (2)$$

h i j d k e t t ector l g the x y nd axes respect ly

Equipotential surface As the name mpl es th an im g nary su f c so d awn in an ele t ic field th t ll po ts it a e t th m pot ti l Thus electrical) w k i d i m ving a ch ge f m pl e to pl n qu potential s r f Electr c l es of f e ar e erywh re t r ht angles t q p te t al rfa e [R P WI]

Bibliog phy R P W nch *El t icity nd Mag* ... 1 5

Potential barrier

A field ((which u u d the i m n le s and tend t keep bombard ng part le ut of the fu If the l omb di g p t el i p ti ly cha ged, +Z t ill fe l th C l mb lect o t i c repul a t h h e r po ds p tent l en gy k r l/ wh m the d t e f om the center f th n cleus Z i the t m umb f the bomb d g p t l d i the h rg f the pr m Th pot t l b r i e t th d e m l r (Th m imum he ht of th Coulomb b rr at th n le r f c whe e

$$\frac{ZZ'e^2}{R}$$

R be g th rad f th nu l and Z t ha g f p t n th b rr e bo t 4 M f r n ... f th ord t p rt le les tha the b rr ... n i th u l s nly by irtu f ... lled the qu t m mechan c l t nn l ef

The an dd t al pot t l b er call d ... f l th h g d d n ut al ... t t l gula m m nt m ... t th n le (l i th a g la ... nt m n mbe and h Pl ck c ... Th ent f gal b ... t th trif gal f ...

t onal to $l(l+1)$ and ari s as $1/$ thus it may be a d to be th nner than the Co lomb barri r *S e* NUCLEAR STRUCTURE SCHOTTKY EFFECT [D H W]

Potential difference

The p tent l diff re e $V_A - V_B$ betwee tw po nts A nd B n electric field defi ed s th ch nge in p t tial nergy of a t t ch ge when t i mo ed b twee the two p nt di ided by th ma itude nd gn f the t t ch rge A test charge on who m gnit d i small en ugh that it p e en e does n t nfl e ce the fi ld S nce lectri field i t n ity E i for e pe unit charge a d po-t t al d ffer e $V_A - V_B$ s w rk per u harge E and $V_A - V_B$ re l ted to each other by the li e nteg al

$$V_A - V_B = -\int_{(B)}^{(A)} E \cos\theta \, ds$$

wher ds i an eleme t f p th le gth fr m B to-w d A nd θ i th ngl bet een the ve tors E d ds S ELECTRIC FIELD

Th o ept f p t tial d fference s imp ta t o n el ctri c r it lculati s wh e on ually de e t by s ying th t th p te ti l d f f rence $V_A - V_B$ b twe n tw poi ts A nd B the nit the w rk t n t ch rg w ll do i fl w n f m A t B In ci cu t a ltmete w ll a d e t m a ure of p t t l d ff e c S Po ENTI L ELECTRIC [R P WI]

Potentials (mathematics)

S pp e that tuat d at h p int of re i n R i p e ther is a e t that q a tity wh ch h b th magn t de a d d e t n It the d th t ther s a ect r fi ld n th eg on R An e mpl gi by the ect r fi ld cons st g of the w d el ty nd direct t e h point n eg n R the s rfa f the rth A ect r fi ld ep e ted a re t ngul d te y tem by an p es i n of the f rm $a(x,y,z)i + b(x,y,z)j + c(x,y,z)k$ where j k e it t the di t on of the x y xes r spe t ely S pp e the e si gl f t n $\phi(x,y,z)$ ch th t $\partial\phi/\partial x = a$ $\partial\phi/\partial y = b$ $\partial\phi/\partial z = c$ Then the e t r field des bed complet ly by th n gle fu t on ϕ d th s e th fi ld lled the g d ent f ϕ N t ery ect r fi ld i gr d t field i e f om the f t that $\partial^2\phi/\partial x\partial y = \partial^2\phi/\partial y\partial x$ n ry d t i $\partial a/\partial y = \partial b/\partial x$ S m la d t n lat g a nd c nd l t ng b a d m t al hold

Gravitation Newt s l w f g it t ng es ri to ect field in the f ll w ng way Imag e a b dy M f n t ma it at d at the r g O f a ct gul r di t y t m d a th body M' of t ma t at d at a po t $P(x,y,z)$ f ... A c d g t Newt n law th f e f ttr t n bet een M nd M' wh ch n e ly p p t al t th q e f the d t ... $\sqrt{x^2+y^2+z^2}$ b tw the bod F r e n n the un t r l ted th t th m gn t de ...

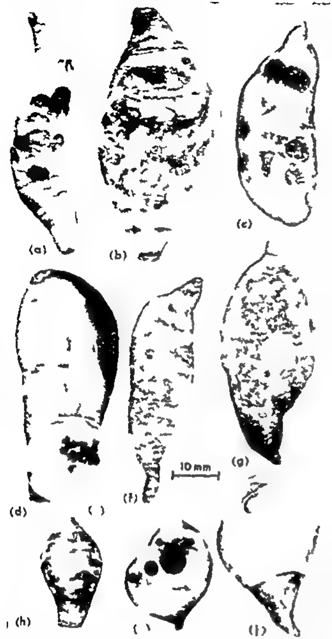


Fig. 3 Some important sweet potato diseases (a) Black rot (b) Soft rot (c) Soil rot (d) Internal cork ( ) Section through internal cork affected root (f) Root knot (g) Java black rot (h) Scurf (i) Circular spot (j) Charcoal rot (L a Agric lt I Exp r me t Stat)

product that is similar to the Irish potato chip but higher in vitamins and carbohydrates The most recent development is the making of sweet potato flakes similar to corn flakes which can be used as cereal in pie filling in doughnuts and in casserole form In addition many livestock growers use fresh and dehydrated sweet potatoes for feeding swine poultry and dairy cattle The sweet potato stimulates milk production and increases the vitamin A content of the milk

True yam The true yam *Dioscorea* includes both edible and medicinal varieties The latter are grown primarily for their cortisone as steroid A large number of cortisone yams are grown in the United States particularly in Louisiana *See* BREEDING (PLANT) CAROTENOID STEROID VEGETABLE GROWING VITAMIN A *see also* POTATO IRISH
[J C M]

Diseases Sweet potato diseases caused by fungi nematodes and viruses affect both the plants growing in the field and the edible root in storage and transit Diseases incited by the different fungi are black rot stem rot soft rot soil rot scurf circular spot Java black rot charcoal rot foot rot root rot mottle necrosis leaf blight leaf spot white rust and true rust The primary nematode disease is root knot Virus diseases important in sweet potato production mainly since 1940 are mosaic feathery mottle internal cork mottle leaf dwarf and others still unidentified

Disease control of any great importance in successful production and distribution of sweet potatoes is difficult because sweet potatoes are propagated vegetatively Essential control practices are selection of disease free roots for propagation chemical treatment of selected roots to destroy unseen traces of fungi and crop rotation to reduce soil infestation Soil treatments with fungicides or nematocides sometimes are necessary to rid infested soils of disease producing organisms Since 1940 resistant varieties obtained through breeding and selection have aided in control of stem rot and to some extent soil rot black rot and root knot World wide search for disease resistant strains among the numerous sweet potato types available combined with breeding programs should result in development of more resistant varieties *See* NEMATODA PLANT DISEASE PLANT VIRUS *see also* FUNGISTAT AND FUNGICIDE [W J M]

Potential electric

At a given point in an electric field the electric potential is the potential difference between that point and a place that is arbitrarily said to be at zero potential (*see* POTENTIAL DIFFERENCE) Frequently it is convenient to consider that the earth is at zero potential and this choice is made when convenience is served as it usually is in a circuit analysis In other cases particularly in electrostatic field the problem is simplified if the potential is taken to be zero at a place infinitely far removed from the charges which produce the electric field Using the latter choice the potential V at a point P is the work per unit charge required to move a positive test charge from infinity to P (a test charge is one whose magnitude is small enough so that its presence does not distort the field being studied) Since electric field intensity F is force per unit charge it follows that V at point P is given by the line integral

$$V = \int_{(\infty)}^{(P)} \mathbf{F} \cdot d\mathbf{s} = \int_{(\infty)}^{(P)} F \cos\theta \, ds \qquad (1)$$

where ds is a vector element of path length directed along the chosen path from ∞ toward P and θ is the angle between the vector E and ds *See* ELECTRIC FIELD

Potential is a scalar point quantity since it has a magnitude only at every point in an electric field so a potential function V for a particular problem is a scalar equation which expr [illegible]

funct of the coordi ates the electr t t c field (ELECTRO TATICS)

Principle of superposition Th states th t f r an c fig rat o f h ges th pote tial t a p t m a lect tati fi ld s the al braic m f th pote t l that e ch ch g alon w ld pro d t the p int. S n th s calls f r an algeb a c sum (ath than the ect sum equ ed f the calcul ti of E) it i fte er t et i p the potent al fun ti n f a p rti ul r phy cal pr b lem th to n t ct d ectly th funct for E Then, th th pote t al funct n kn wn the dif ferenti l el t h p $E = -\text{grad } V$ the on t r f al ul ti n of E r the tha th te ral e lat hip [Eq (1) If V i exp e sed in C tes an co din t th gr d e t eq to m

$$E = -\left(\frac{\partial V}{\partial} + \mathbf{j}\frac{\partial V}{\partial y} + \mathbf{k}\frac{\partial V}{\partial}\right) \qquad (2)$$

h e i, j nd k a e unit cto lo g th x y d z axes, respe t ly

Equipotential surface As th ame implie this ag n ry u f ce so d wn i an ele t ic field th t ll po t t th s me pot t al b elect l w k i d ne i m ng a u e f m pl e t pl o a equ pote tial ur Elect c l s f f e ev ywh e at right angles to q pote t l rf ce [R P W I]

Bibl g phy R P W n h El ctricity d Mag m 1955

Potential barrier

[illegible] h h u d the t m u leus A te d t keep b mb ed part le t f h u leu If the b mb d g p ti l p t ly charged +Z t ill f el th C lomb elect t t c p l t h h r p nd p t nt l en gy l h a l/ h r i th d t n f m the center f th n cle s Z i th t m c umb f th bomb d g p t l d e the h ge f th proton Th p t ti l b r i ea t the dge of the] and th er me by th att a n f c Th m imum he ht of th Coulomb barr at th le r s f c whe e

$$\frac{ZZ}{R}$$

R b gth r d (th n) d Z t ch ge f [illegible] th l a r abo t 4 M f r n [illegible] m If th i ti l k et n n f th d nt p t l les th the b r [illegible] t th nu l s nly by irtu f [illegible] ll d th quant m m chan c l t n l f

Ther n dd t l pote t l b c ll d [illegible] f z l b r f both h g d d n t al [illegible] th h a l t l a g la m me t m [illegible] t th l (l i the a g la [illegible] t m n mbe and h Pl ck [illegible] th t f g l b r p t w k [illegible] t f g l f It i p p

t nal to $l(l+1)$ and arre s l/ thus it m y be sa d to be thi er th n th Co lomb barr er S NUCLEAR STRUCTURE SCHOTTKY EFFECT [D H W]

Potential difference

The p tenti l diff en e $V_A - V_B$ betwee tw poi ts A and B n n ele t ic field defi ed s th ha ge i p t tial ergy of a test ch ge when t is m ed between the two p nt divid d by th m g i de nd gn f the t st charge A te t ch rg ne who ma it de is mall n gh that it p en doe t fl ence the field S nce lectri field i t sity E i fo ce pe unit charge d po te t l d ffer n e $V - V$ s w k per u it harge E and $V - V$ a e r l ted t each other by the li tegr l

$$V - V_B = -\int_{(B)}^{(A)} E \cos\theta \, ds$$

wher d i an leme t f p th le gth fr m B to wa d A nd θ i th ngl b twe the v tor E d ds S ELECTRIC FIELD

The n ept f p t nti l d ffere ce s an imp t nt one n el tri cir t lc lati ns wh e o ally de e t by s i g th t the pot ti l d f f e $V - V$ betwe n tw p i ts A d B n th c uit the w k u t ch r w ll d in fl w g f m A t B In c cu t a v ltmete w ll g a d re t m ure of pot t l d ff e ce S PO ENTIAL, ELECTRIC [R P W I]

Potentials (mathematics)

S pp e that tuat d t e h p i t f r ion R i p e the is to th t a qu tity wh h h b th m g t de a d d r t n It the d th t the a e t field n th eg on R An mpl s g n by the e t field ns st ng of the w d el ty nd di ect n t h poi t n a eg n R the f e f the th A v ct r fi ld i ep e ted i a e t ngul r c o di ate y tem by an p es f the form $(x\,y\,z)\mathbf{i} + b(x\,y\,z)\mathbf{j} + c(x\,y\,)\mathbf{k}$ whe e j k a e i t ec t the d e t o f th x y xes r pec t ely S pp e ther gl f n t $\phi(x\,y\,z)$ ch th t $\partial\phi/\partial x =$ $\partial\phi/\partial y = b$ $\partial\phi/\partial =$ The the t fi ld de c bed mplet ly by the i gle f t on ϕ d th s ca e th fi ld is lled the g d nt f ϕ N t ery e to fi ld s a gra d t field from the fa t th t $\partial\phi/\partial x\,\partial y = \partial\phi/\partial y\,\partial x$ ry c d t n s $\partial/\partial y = \partial b/\partial x$ S m la d t r l t g a nd d r lati g b a d m t l hold

Gravitation Newt s l w f g tat n g r se t t r fi ld n the f ll wi g w y Im gi a b dy M f n t m tu ted at th o igi O of a t g la c d n te sy t m nd n th body M f n t m it i d t p t $P(x\,y\,z)$ f A d g t N wt n law the e t f ce f it t n b tw n M a d M wh h i ly p t n l t th q f the d t nc $\sqrt{\;+y\;+z}$ b tw th l d e F r en e th t lect d th t th m g de f th f qu l t l/ Th mp nt f

the force at P are

$$-\frac{1}{r^2}\cos\alpha - \frac{1}{r^2}\cos\beta - \frac{1}{r^2}\cos\gamma$$

where α β γ are the angles that the line OP makes with the coordinate axes These may be written also as

$$-\frac{x}{r^3}\mathbf{i} - \frac{y}{r^3}\mathbf{j} - \frac{z}{r^3}\mathbf{k}$$

As the body M_2 moves throughout space a vector field or force field is generated This is usually designated the Newtonian or gravitational field A simple calculation shows that the function $\phi = 1/r$ has as its gradient the gravitational field In other words by means of a single function the gravitational forces due to a unit mass at a single point are completely described This function is called the unit gravitational potential or simply the potential

In the idealized situation just described the masses M_1 and M occupy single points in space Let M_1 occupy a domain D in space and let $\rho(\xi\,\eta\,\zeta)$ be the density of M_1 at each point $(\xi\,\eta\,\zeta)$ of D Once again M_2 is a unit mass located at a point $P(x\,y\,z)$ not in D The mass M may be decomposed into elementary pieces and the gravitational potential at P due to M will be the sum of the potentials of the individual parts By the usual limiting process of calculus the potential ϕ is given by

$$\phi(x\,y\ ) = \iiint_D \frac{\rho(\xi\,\eta\,\zeta)\,d\xi\,d\eta\,d\zeta}{[(x-\xi)^2+(y-\eta)^2+(\ -\zeta)^2]^{1/2}} \qquad (1)$$

The gradient of $\phi(x\,y\,z)$ yields the gravitational force field due to the mass M at each point of space exterior to D Although the integrand in (1) becomes singular for points $P(x\,y\,z)$ within D the integral itself nevertheless has a finite value Thus it is possible to consider the potential of solid objects throughout the entire space

A simple calculation shows that the function $\phi = 1/r$ satisfies the Laplace equation

$$\frac{\partial^2\phi}{\partial x^2} + \frac{\partial^2\phi}{\partial y^2} + \frac{\partial^2\phi}{\partial z^2} = 0$$

at all points except $r = 0$ Similarly the integral (1) satisfies the same equation at all points not in D Thus the study of gravitational field is intimately connected with the study of a particular partial differential equation—the Laplace equation This equation arises in many branches of mathematical physics and hence an immediate analogy is drawn between the Newtonian potential and potentials which arise in the study of electricity magnetism and fluid flow

Electricity The force field due to the attraction and repulsion of electric charges admits of an analysis similar to that for the gravitational potential The main distinction between Coulomb s law and Newton s law lies in the fact that similarly charged electric particles repel each other The potential function for two particles each of unit charge is either $1/r$ or $-1/r$ according as they are of opposite or of like charge If one considers the field due to a number of charges some positive and some negative care must be taken in regard to the sign in computing the electric potential

Magnetism The field of force due to a magnet is somewhat more complicated than those due to masses or electric particles Under ordinary considerations of a magnet it is essential that there be both a north and a south pole There is no parallel to a point unit mass or a positive electric charge of one unit For this purpose it is necessary to introduce the idealized concept of a magnetic particle Imagine one pole of a magnet located at a single point $P_0(x_0\,y_0\,z_0)$ with an attracting strength m and the other end of the magnet at the point $P_1(x_1\,y_1\,z_1)$ with attracting strength $-m$ The potential function at a point $P(x\,y\,z)$ in space due to this magnet is given by the function

$$\phi = (x\,y\,z) = m/r_0 - m/r_1$$

where

$$r_0^2 = (x-x_0)^2 + (y-y_0)^2 + (z-z_0)^2$$
$$r_1^2 = (x-x_1)^2 + (y-y_1)^2 + (z-z_1)^2$$

In other words idealized magnets also follow Newton s or Coulomb s laws with strength of poles replacing masses and charged particles One can denote by d the length of the segment P_0P_1 let the point P_1 approach P_0 along the line segment P_0P_1 and let m approach infinity in such a way that $m\,d$ is always equal to a constant μ The function ϕ will approach a limit which is a potential function The quantity μ is called the moment of the magnetic particle at P_0 It is clear that ϕ also depends on the direction along which P_1 approaches P_0 and this direction is called the axis of the particle It is not difficult to see that the potential of a magnetic particle is the moment times the directional derivative of the function $1/r$ in the direction of its axis The potentials due to curved surfaces and solids made up of magnetic particles are obtained by integration as in the case of gravitational potentials

Heat conduction Heat conduction in a solid is governed by the partial differential equation

$$\frac{\partial\phi}{\partial t} = \frac{\partial^2\phi}{\partial x^2} + \frac{\partial^2\phi}{\partial y^2} + \frac{\partial^2\phi}{\partial z^2}$$

In the steady state flow of heat $\partial\phi/\partial t = 0$ and the solution independent of time satisfies the Laplace equation Thus the problem of determining the steady state flow of heat in a body is equivalent to the problem of finding a potential function under appropriate boundary conditions

Fluid flow Suppose a fluid flows through a region R in space Let $u(x\,y\,z\,t)$ $v(x\,y\,z\,t)$ $w(x\,y\,z\,t)$ be the components of the velocity vector at the point $P(x\,y\,z)$ at time t If the flow is stationary the functions u v w do not depend on t If in addition the fluid is incompressible and the flow irro

tr al that i fre of ortices th re will exi t a potential f nct on ϕ s ch that its gradient is the velocit field hich d bes the flow

Other concepts Many problems of p te tial the ory become impler if a restriction t two dim n made Supp wire of con ta t linear d sity P i itu ted along the z ... can as sume th t it is infinitely long exte d g f m $z = -\infty$ to $z = +\infty$ The force fi ... t a po nt P(x, 0) i cal ulated t be $2\rho/r$ where $r =$ ... d i drected along th l ne OP The potent l h h yi lds th s force field is $\phi(x\, y) =$ ... ln (1) a d th l gar thm c p t t l play same le in tw d m ns n th t the fu ct n 1 does i the th ee-d me sional ca e I two ari able th f nction ln $(1/r)$ sat fies the Lapl c equation f r $r \neq 0$ while the fu ct on $1/\sqrt{x + y}$ d not.

An import t co ept pote t l theory is th c n f q p te t al u face If $\phi(x\,y\,)$ is a po tential fu t then general $\phi(x\, y\, z) = C$ where C t c n t nt defines a s rf m sp ce F an lyt geom try ... kn wn that if F(x, z) 0 any u f e the vect r

$$\frac{\partial F}{\partial x} i + \frac{\partial F}{\partial y} j + \frac{\partial F}{\partial} k$$

... n rm l t the su face t the p int ( ) In the c se f a potenti l fun t th ... mply

$$\frac{\partial \phi}{\partial} + \frac{\partial \phi}{\partial y} j + \frac{\partial \phi}{\partial z} k$$

is the grad e t fi ld f the potential Th me ns ... t e ry po t f th rf e $\phi(x\,y\,) = C$ the f ce r flux e t s pe pe d ul to th r ... There f c s a e call d equ p tent l lines and th l g e t nte e t i ... oblem ... f d fi a d he t nd t n ... exh b t the l e relat on h p b twee ... the Lapl c q at o (ll d ha m n c ...) a d pote t al a sk t ... w ll be gi ... t e ery ha m n c fun tion may be ... ed a a m f potent al Den te by Δ ...

$$\frac{\partial}{\partial x} + \frac{\partial}{\partial y^2} + \frac{\partial^2}{\partial}$$

... R ... g n with mooth bo nd ry S a d n ... ut n rmal to S the foll w ng iden ... f G e n the m

$$\iiint_R (\Delta - \Delta u)\, dl = \iint_S \left(\frac{\partial}{\partial} - \frac{\partial u}{\partial} \right) dS$$

(2)

... u a d ... wh ch have ... dd ri at es ... a eg nt i ng R ... be a fi ed p nt f R and the d ... $P(\,y, z)$ ... P Th lect $1/$ ... (2) b ...

gularity at P Howe (2) t ll holds if a small sphere about P i d leted f om R and to the boundary S is added the surface of th s sphere After ome red ct n the esulting f rmula s

$$(x_0\,y_0\,z_0) = -\frac{1}{4\pi} \iiint_R \frac{\Delta u}{} \, dl + \frac{1}{4\pi} \iint_S \frac{\partial u}{\partial n} \frac{1}{} \, dS - \frac{1}{4\pi} \iint_S u \frac{\partial}{\partial} \left(\frac{1}{r} \right) dS$$

If now u is harm c the first i te al o the right anishe d the rel t on

$$u(x_0 y \quad) = \frac{1}{4\pi} \iint_S \frac{\partial}{\partial n} \frac{1}{r} \, dS - \frac{1}{4\pi} \iint_S u \frac{\partial}{\partial n} \left(\frac{1}{} \right) dS$$

follow The first int gral repr ent the Newtonia p tential d e to rf ce S f de ty $\partial u/\partial$ while th econd tegral s the p t tial f a face S f magneti ... with m gnetic mome t $u(\,y z)$ S CALCULUS OF VECTORS DIFFERENTIAL EQUATION LAPLACE S DIFFERENTIAL EQUATION OPERATOR THEORY POTENTIALS (PHYSICS)

[M H P]

Bibl g aphy O D K llogg *Fo dations of P te ti l Theo y* 1929 H Poincar *Th o ie d P tent el Neut e* 1899

Potentials (physics)

Potential n phy a e of tw k d (1) meas ure f ... g of a q nt ty a a lable for p ssible se and (2) fu ti ns who e t ... hang a e the pr m ry q ntit of a phy c l th ory Va s the f egoing d fi it n i t i ar ely b o d eno gh to lude all rre t u ag f the w d pot t l I the lde t nd m t c mm n appl a tions b th se (1) d (2) apply d i sens (2) the p t t al i ngl f ti from wh ch a ctor h as f ce a el city is deri ed In the ew a d b d u age A potenti l f B if s m mb natio f th parti l d ati e of A quals B e p t ... of phy al nt pretat on In many e pe t (1) lead t or is epl c d by ... n rv t n pr ciple a rt ... the e i t e f q tity wh h mai s chang d The con erved q ant ty n ome i defin d i term f th pote t al and i ome c se i t Sometim the e t f a p t nt l le ds l t me pr c ple of c my whe eby m q a t ty d fined by the a d of th p t t l i le d g t th p rti l r phy c l theo y th n t w uld be f that th y d d t hold

It c n ot j tly be d th t th w d p t tal t d f ny phy l c ept Rath r as n w u ed t ef l ely t the mathem t cal s mpl ficat f f mulas th t met me ... his wh n s me f th d ffe e t l quat n f a the ry ar repl d b the gen al ol t n t rm f a b t ry f t n Th e f ct ns the c lled p t nt l

Ab e ce f un fyi g c ncept make an ... mer t of typi l c s th nly bl way to ...

Potentials in mass point mechanics A body of constant ma s M near the earth s surface obeys the law of conservation of energy

$$\text{Total energy} = T + U = \text{const} \qquad (1)$$

Here T is the kinetic energy arising only from the motion of the body $T = \frac{1}{2} Mv^2$ where v is the speed The energy U is a potential energy arising only from the location of the body $U = Mgz$ where z is the height above some arbitrary level and g is the constant acceleration of gravity Lo s of ome potential energy results in gain of an equal amount of kinetic energy and vice versa The force $\mathbf{F}$ which acts on the body is given by $\mathbf{F} = -\text{grad } U = -\partial U/\partial \mathbf{r}$ where $\mathbf{r}$ is the position vector Both aspect (1) and aspect (2) of the def inition of potential are illustrated here

More generally consider a system of n mass points with masses M_k and position vectors $\mathbf{r}_k$ A function $U(\mathbf{r}_1\ \mathbf{r}_2\ \ \ \ \mathbf{r}\ )$ is said to be a poten tial energy of the system if the force acting upon the kth mass point is given by

$$\mathbf{F}_k = -\text{grad}_k\, U = -\frac{\partial U}{\partial \mathbf{r}_k} \qquad (2)$$

Therefore the equations of motion are

$$M_k \ddot{\mathbf{r}}_k = -\frac{\partial U}{\partial \mathbf{r}_k} \qquad k = 1\ 2 \qquad n \qquad (3)$$

Integration of Eqs (3) again yields the theorem of con ervation of total energy in the form of Eq (1) where

$$T = \frac{1}{2} \sum_{k=1} M_k \dot{r}_k^2$$

This result illustrates not only a pects (1) and (2) but also the simplicity of specifying the mo tion of the sy tem by means of the single function U instead of the n vectors $\mathbf{F}_k$ *See* ENERGY

One principle which may erve as the basis of statics states *that the equilibrium position of a* conservative system is uch that its potential en *ergy a sumes the least value po sible* There are several generalizations of this idea to dynami s For example let the conservati e system considered be de cribed by $3n$ generalized coordinates q_k The kinetic potential $L(q_1 \qquad q_1\ q \qquad q\ )$ is defined by $L = T - U$ *The motion of the sy tem is* such as to give the total kinetic potential its least *possible value* A mathematical expre sion for this requirement is

$$\frac{d}{dt}\frac{\partial L}{\partial \dot{q}_k} - \frac{\partial L}{\partial q_k} = 0 \qquad k = 1\ 2 \qquad 3n \qquad (4)$$

See LAGRANGE S EQUATIONS

Gravitational potentials One expression for the classical law of univer al gravitation is *that there* exi ts a potential energy $U(P)$ of the form

$$U(P) = G \int \frac{dm}{r(dm\ P)} \qquad (5)$$

where $r(dm\ P)$ is the di tance from the elem ma s dm to the point P Here G is the con universal gravitation The integration is out over all pace both di crete and cont ma ses may be included When all ma es a *crete the theory becomes a pecial case of t* pressed by Eqs (3) When ma s is mooth tributed in space so that $dm = \rho dv$ where ρ density and dv is an element of volume it shown from Eq (5) that

$$\nabla^2 U = \frac{\partial^2 U}{\partial x^2} + \frac{\partial^2 U}{\partial y^2} + \frac{\partial^2 U}{\partial z^2} = 4\pi G\rho$$

In empty space

$$\nabla^2 U = 0$$

The force acting on a unit ma s present in b influencing the gravitational field is $-\text{grad } U$ extensive mathematical developments ba Eqs (6) and (7) con titute potential theory GRAVITATION

In general relativity the metric tensor of time is supposed to be determined by the di tion of energy and momentum Its ten compo g_{km} are called gravitational potentials The e tities do not conform to the definition dir rather their name arises from the fact that po sible to define from them mathematical quantity which reduces in the la sical appro tion to the classical potential U which a Eq (6) *See* RELATIVITY

Fluid potentials If the motion of a fluid or deformable substance is such that there exi function ϕ giving the velocity $\mathbf{v}$ as follows

$$\mathbf{v} = -\text{grad } \phi$$

th n ϕ is said to be a velocity potential A p kind of motion called irrotational motion is *acterized by Eq (8) In such a motion the* portions of the material are not spinning th they may circulate If the substance is incom sible then $\nabla^2 \phi = 0$ compare Equation (7) this ca e the motion has less kinetic energy any other one corresponding to the same charge of matter through a fixed bounding face *See* LAPLACE S IRROTATIONAL MOTION

More generally if the acceleration a satisfi relation uch as Eq (8) $\mathbf{a} = -\text{grad}$ I then called an acceleration potential Again a pe kind of motion is characterized this time circulation of velocity around any closed ring particles remains unaltered Th is a con erva principle

Virtually all of the science of hydrodynam and aerodynamics concern moti ns of the e ki The acceleration potential may generalize the tential energy since in me conditions V + $\int dp/\rho$ where V is a potential energy an is the pre ure In a steady motion along e streamline

$$\tfrac{1}{2} v^2 + \Phi = \text{c n t}$$

This is a theo em f nservation of energy ome- ... Eq (1) F r a motion having a velocity p ... the con t t i Eq (9) has the same ... f e h tre ml S e STREAMLINE FLOW

Elastic and plastic potentials In a perfectly ... body the stress di tribution f inte or ... es solely e p e to the def rmation ... f m the free or natural state Th e ... d p od ing the def mation is a ail ... f reve it th s work is the stored en ... f t ble m ure of stress T and strain E ... then the stored energy $F(E)$ is also ... potential f the stres as i expressed by the ... f rmula

$$T = \frac{\partial F}{\partial E} \qquad (10)$$

... mılar f rm la holds in some theor es of ... cept th t F d p nd pon the eloc ty ... up n the def mation ... all d a plast c pote t l

Thermodynamic potentials Th ter l energy ... elated to the sto ed e ... theory While a athe ge e al ... ly the case of a simple ... The nt nal energy i then ... by th sp cif olume a d the spe ... entrop η ... $(v\,\eta)$ The tem ... θ nd the p es u e π a e then btained ... a p t ntial

$$\theta = \frac{\partial}{\partial \eta} \qquad \pi = -\frac{\partial \epsilon}{\partial v} \qquad (11)$$

... th modyn m c p te ti ls may be in ... The mple t a the f ee energy ψ the ... χ and the f ee nthalpy ζ d fined s

$$\begin{aligned} \psi &= \epsilon - \eta\theta \\ \chi &= \quad + \pi v \\ \zeta &= \epsilon + \pi v - \eta\theta \end{aligned} \qquad (12)$$

... $-\psi - \chi + \zeta = 0$ The f nct ns ... $\psi(\theta\ )$ $\chi(\eta\ )$ and $\zeta(\theta\ \pi)$ e the ... pot t al the that all thermo- ... m y be btai d as c mb ... any on of them S THERMODYNAMIC PROCESSES

Electromagnet c potentials S n e the law of ... bet een h rg ... ts s f th ... t al f rm as that betwe n m ss- ... lect o t tic p te t l of th ... f nct n U g en b Eq (5) e ... dm eplaced by an ... which may a m negat e ... nd th con t nt G is r ... Th s the wh le ... potent l ppl cable by ... d ng t le tr tati ... bject ma be pp ached fr m a m r ... f th ... g th el t mag et fi ld m y be written in the f ms

$$\operatorname{div} \mathbf{B} = 0 \qquad \operatorname{curl} \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t} \qquad (13)$$

where B the m g t c ndu ti n nd E is the electric fi ld inte ty The first f these condi t n regard d as pa t al diffe nt al equation has the gene l luti n

$$\mathbf{B} = \operatorname{curl} \mathbf{A} \qquad (14)$$

whe e the arb t ry funct n A s call d the vector potent l Subst t t ng Eq (14) into th second of Eq (13) y elds

$$\operatorname{curl}\left(\mathbf{E} + \frac{\partial \mathbf{A}}{\partial t}\right) = 0 \qquad (15)$$

The general lution of thi p tial d fferential equ t on is

$$\mathbf{E} + \frac{\partial \mathbf{A}}{\partial t} = -\operatorname{grad} \Phi \qquad (16)$$

Th the ele t o tati p tenti l pecial case f the g e al el t dynam c c l p tential Φ The p tent als Φ nd A h e to be epl ced by suitabl t ns p tenti l wh ele trodyn mics i expre ed n a f d m nally in a ant f r malism S e MAXWELL S EQUATIONS

Potentials of arbitrary fields The re r io s represe t ti ns of an rb t ary ector field c me of the e e

$$\begin{aligned} &= \operatorname{grad} H + F \operatorname{grad} G \\ &= \operatorname{grad} M + \operatorname{grad} A \times \operatorname{grad} L \\ &= -\operatorname{grad} S + \operatorname{curl} \mathbf{P} \end{aligned} \qquad (17)$$

The exi te ce of the ar s potentials de ot d by capital lette n th e f m las r flects geomet c pr p t es of ve t field n ge al nd find ap- pl t on n part cula th t s c o di t h w th e g metr p t es e g n phy ical in terp et t on The e re m l p te t ls fo te sors

Alth gh formul s (17) are wr tten f th ee d m ns on l sp e s m la p te t al ep e ent tio re l d in p c f y d m s n d n pa t ular f pa tum

F r e ample f d i t r de ty and $\mathfrak{h}$ i a b ect t fy th ervat n p i ciple

$$\mathrm{D}\ \ \mathfrak{s} = 0 \qquad \mathrm{Curl}\ \mathfrak{h} = 0 \qquad (18)$$

e pe t ely th th ee st p te t l β d α ch th t

$$\mathfrak{s} = \mathrm{D}\ \ \beta \qquad \mathfrak{h} = \mathrm{Rot}\ \alpha \qquad (19)$$

where Di C l d Rot ppropriately de fin d d ff ent l op R t f r ample s d fin d n th wo k by Sch ute l t d n the bibli g raphy

Retarded potentials A pec l ki d of f u d me so l p tenti l app a s n th ma y the ... es th t lead t the eq tio f r li ea wa e

Potentials in mass point mechanics A body of onstant mass M near the earth s surface obeys the aw of conservation of energy

$$\text{Total energy} = T + U = \text{const} \qquad (1)$$

Iere T is the kinetic energy arising only from the notion of the body $T = \frac{1}{2} Mv^2$ where v is the peed The energy U is a potential energy arising nly from the location of the body $U = Mgz$ here z is the height above some arbitrary level nd g is the constant acceleration of gravity Loss f some potential energy results in gain of an qual amount of kinetic energy and vice versa he force $\mathbf{F}$ which acts on the body is given by $= -\text{grad } U = -\partial U/\partial \mathbf{r}$ where $\mathbf{r}$ is the position ector Both aspect (1) and aspect (2) of the def ition of potential are illustrated here

More generally consider a system of n mass oints with masses M_k and position vectors $\mathbf{r}_k$ A inction $U(\mathbf{r}_1 \ \mathbf{r}_2 \quad \mathbf{r} \ )$ is said to be a poten al energy of the system if the force acting upon ie kth mass point is given by

$$\mathbf{F}_k = -\text{grad}_k U = -\frac{\partial U}{\partial \mathbf{r}_k} \qquad (2)$$

herefore the equations of motion are

$$M_k \ddot{\mathbf{r}}_k = -\frac{\partial U}{\partial \mathbf{r}_k} \qquad k = 1 \ 2 \qquad n \qquad (3)$$

itegration of Eqs (3) again yields the theorem f conservation of total energy in the form of Eq 1) where

$$T = \frac{1}{2} \sum_{k=1} M_k \dot{r}_k^2$$

his result illustrates not only aspects (1) and 2) but also the simplicity of specifying the mo on of the system by means of the single function instead of the n vectors $\mathbf{F}_k$ *See* ENERGY

One principle which may serve as the ba is of atics tates that the equilibrium position of a onservative system is such that its potential en gy assumes the least alue possible There are veral generalizations of this idea to dynamics For cample let the conservati e system considered be escribed by $3n$ generalized coordinates q_k The netic potential $L(q_1 \quad q_3 \ q \quad q \ )$ is efined by $L = T - U$ The motion of the system is ich as to give the total kinetic potential its least sible value A mathematical expre sion for this quirement is

$$\frac{d}{dt}\frac{\partial L}{\partial \dot{q}_k} - \frac{\partial L}{\partial q_k} = 0 \qquad k = 1 \ 2 \qquad 3n \qquad (4)$$

ee LAGRANGE S EQUATIONS

Gravitational potentials One expression for the assical law of uni er al gravitation is that there xists a potential energy $U(P)$ of the form

$$U(P) = G \int \frac{dm}{r(dm\ P)} \qquad (5)$$

where $r(dm\ P)$ is the distance from the element of ma s dm to the point P Here G is the con tant of universal gravitation The integration is carried out over all pace both discrete and continuou masses may be included When all mas es are dis crete the theory becomes a pecial case of that ex pressed by Eqs (3) When ma s is moothly dis tributed in space so that $dm = \rho dv$ where ρ i the density and dv is an element of volume it can be shown from Eq (5) that

$$\nabla^2 U = \frac{\partial^2 U}{\partial x^2} + \frac{\partial^2 U}{\partial y^2} + \frac{\partial^2 U}{\partial z^2} = 4\pi G \rho \qquad (6)$$

In empty space

$$\nabla^2 U = 0 \qquad (7)$$

The force acting on a unit mass pre ent in but not influencing the gravitational field is $-\text{grad } U$ The extensive mathematical developments ba ed on Eqs (6) and (7) constitute potential theory *See* GRAVITATION

In general relativity the metric ten or of pace-time is supposed to be determined by the distribu tion of energy and momentum Its ten components g_{kr} are called gravitational potentials The e quan tities do not conform to the definition directly rather their name arises from the fact that it is po sible to define from them mathematically a quantity which reduce in the clas ical approxima tion to the classical potential U which satisfies Eq (6) *See* RELATIVITY

Fluid potentials If the motion of a fluid or other deformable substance is such that there exists a function ϕ giving the velocity $\mathbf{v}$ as follows

$$\mathbf{v} = -\text{grad } \phi \qquad (8)$$

then ϕ is said to be a velocity potential A special kind of motion called irrotational motion is char acterized by Eq (8) In such a motion the small portions of the material are not spinning though they may circulate If the substance is incompres sible then $\nabla^2 \phi = 0$ compare Equation (7) In this case the motion has le s kinetic energy than any other one corresponding to the ame di charge of matter through a fixed bounding sur face *See* LAPLACE S IRROTATIONAL MOTION

More generally if the acceleration a satisfies a relation such as Eq (8) $\mathbf{a} = -\text{grad } \Phi$ then Φ is called an ac eleration potential Again a special kind of motion is characterized this time the circulation of velocity around any clo ed ring of particle remains unaltered This i a con ervation principle

Virtually all of the science of hydrodynamics and aerodynamics concerns moti n of the e kind The acceleration potential may generaliz the po tential energy since in some conditi ns $\Phi = \Upsilon + \int dp/\rho$ where Υ is a potential energy and p is the pre sure In a teady m ti n along each streamline

$$\tfrac{1}{2} v^2 + \Phi = \text{const} \qquad (9)$$

s theorem of c ervation of e rgy ome- it Eq (1) For mot on ha ı ₒ locıty ..l the con tant ı Eq (9) ha the same ı ea h tr amline S STREAMLINE FLOW

tic and plastic potentials In a pe fectly bod th tres r d t bution f nterior arises sol ly in respon to the deformati n rue fr m the f or n tural tate The b e n p d in the def mati n is avail ır r er ing it this w rk th to ed en f t bl me u es of stre T a d strain E ected, th the t red ene gy $F(\mathbf{E})$ is also ntial f r the t ess as is e pre sed by the C f rmul

$$\mathbf{T} = \frac{\partial F}{\partial \mathbf{E}} \tag{10}$$

milr f rmul holds in some theo ıes f ır x ept th t F depend po the lo ty rm t r ther than p the d formation h fun ti n s called pla t c pote t l modynamic potentials Th int nal energy ermodyn m c ı el t d t th t d f ela t ty the ry While r ther g er l nt ı po ble ly the a e f a mple p es nted here Th ı tern l e e gy th ned by the specific v lum a d the sp nt py η so th t $=$ (η) Th t m n d a d th pre s r π e th n btaı d a pot tial

$$\theta = \frac{\partial}{\partial\eta} \qquad \pi = -\frac{\partial\epsilon}{\partial} \tag{11}$$

th r th rmody mı p t t l may be ed. The mple t a th f ee n gy ψ th F x d th f ee thalpy ζ defi ed a

$$\begin{aligned} \psi &= \epsilon - \eta\theta \\ \chi &= \epsilon + \pi v \\ \zeta &= \quad + \pi v - \eta\theta \end{aligned} \tag{12}$$

fore $-\psi - \chi + \zeta = 0$ Th f ct ns $\psi(\theta\ )$ $\chi(\eta\ )$ a d $\zeta(\theta -)$ a e th mic pot t l in the th t ll th rmo- e f t m y b bt ed mb f th d ı t s f any e f th m S e MODYNAMIC P OCESSE

ctromagnet c potentials S ce the l w of f bet ch rg p ts f th mathem t l f rm a th t b tween m s- th t a el t t t c p te t l f th f rm the f nct U en by Eq (5) x nt f h ϵ de wh h m y me n g ti e f tı l es and the ta t G ı l by n l t t t e Th s th wh le ı f Newt n pot t l ı ppl c ble by ka ges f w d t el t t ti s L bject m y be app ached f m m r nd expo t Tw f the f et l on m g th lect m g t c fi ld may

be written n the forms

$$\operatorname{div} \mathbf{B} = 0 \qquad \operatorname{curl} \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t} \tag{13}$$

where B the m gnetic ı d ction a d E is the lectric field inte s ty The fir t of these cond t ns reg ded as a partial d fferent al equati n h s the general sol tion

$$\mathbf{B} = \mathrm{c} \quad \mathrm{l}\, \mathbf{A} \tag{14}$$

where the arbitrary fun t on A is lled the ector potential Sub tit t ng Eq (14) ı t the sec d of Eq (13) yield

$$\operatorname{curl}\left(\mathbf{E} + \frac{\partial \mathbf{A}}{\partial t}\right) = 0 \tag{15}$$

The ge al solut on f this p rt al differenti l quation

$$\mathbf{E} + \frac{\partial \mathbf{A}}{\partial t} = -\mathrm{gr\ d}\, \Phi \tag{16}$$

Thu the ele t ost t c pote t l ı a p al ca e f the eral ele t odynam scala p te t l Φ

Th p t tials Φ and A ha e to b epla ed by u table ten p t nt al when elect dynami ı e pre d in a four d men nally arı t fo mali m S e MAXWELL S EQUATIONS

Potentials of arbitrary fields There a e vari s epresentati of n arb t ry ct fi ld c Some of these e

$$\begin{aligned} &= \mathrm{grad}\, H + F\, \mathrm{grad}\, G \\ &= \mathrm{gr\ d}\, M + \mathrm{gr\ d}\, K \times \mathrm{grad}\, L \\ &= -\mathrm{gr\ d}\, S + \mathrm{cu\ l}\, \mathbf{P} \end{aligned} \tag{17}$$

The tenc f th o p t t l den t d by pit l lette n th f rmula fle ts ge m t pr p rti f ect fi lds ı g e al and fi d ap- pl tio n p t c l the s a rd g to h w th e geomet c p pe ties e n phy cal te p tat Ther are m la p te t al f t n so

Altho gh fo mul s (17) e w tten f th d m ı n l pa e sim lar p tent al rep e nt t on re l d n pa of ny d m s a d p rt ul f p e tum

F e mpl f $\mathfrak{d}$ v t n de ity a d $\mathfrak{h}$ ı b ct s ti fy the ers ti n pri ples

$$\mathrm{D} \quad \mathfrak{d} = 0 \qquad \mathrm{Curl}\, \mathfrak{h} = 0 \tag{18}$$

e pecti ely th the e e st p te t l β d α s ch that

$$\mathfrak{d} = \mathrm{D} \quad \beta \qquad \mathfrak{h} = \mathrm{R\ t}\, \alpha \tag{19}$$

wh D C rl a d R t e pp p at ly de- fi ed d ff t l per t r R t f mpl ı de fi ed ı the w k by Sch t l ted ı the b bl og r phy

Retarded potentials A peci l k d f f r d m l p tent l ppe r ı the many the- r th t le d t th equat f r I n r w

$$\frac{1}{c^2}\frac{\partial^2 W}{\partial t^2} = \nabla^2 W \qquad (20)$$

c being the speed at which disturbances such as waves of sound or light travel (*see* WAVE EQUATION WAVE MOTION) Then

$$W(P\,t) = \frac{1}{4\pi}\oint_S \left[\frac{1}{r}\frac{\partial W^*}{\partial n} - \left(W^* + \frac{r}{c}\frac{\partial W}{\partial t}\right)\frac{\partial}{\partial n}\left(\frac{1}{r}\right)\right] dA \qquad (21$$

where S is a closed surface r is the distance from the point P to dA and the asterisk indicates that *the time t is to be replaced by the earlier time $t - r/c$* This formula which shows precisely how signals traveling at the speed c propagate to the point P conditions formerly holding upon the surrounding *surface S is said to represent the wave* function W in terms of retarded potentials *See* CALCULUS OF TENSORS CALCULUS OF VECTORS POTENTIALS (MATHEMATICS)

Bibliography W V Houston *Principles of Mathematical Physics* 2d ed 1948 O D Kellogg *Foundations of Potential Theory* reprint 1953 H B Phillips *Vector Analysis* 1933 J A Schouten *Ricci Calculus* 2d ed 1954

Potentiometer (variable resistor)

A variable resistance device with three terminals used in electric circuits As shown schematically in Fig 1 the three terminals are the two ends of a resistor (or series combination of resistors) and a movable connection which allows adjustment of the resistance between this movable connection and either end connection The movable connection *often consists of a sliding contact which moves* along the actual resistor element The size or rating of a potentiometer is specified by giving its *total resistance in ohms and the permissible losses* in watts *See* RESISTOR By using only the movable and one fixed connection a potentiometer may be used as a rheostat *See* RHEOSTAT

The term potentiometer is also applied to a precision instrument used to measure or compare electrical voltages for a discussion of this device which depends on the same type of resistor ar-

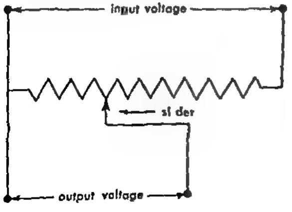


Fig 1 Potentiometer schematic

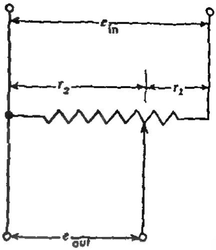


Fig 2 Voltage divider

rangement see POTENTIOMETER (VOLTAGE MEASUREMENT)

Use A potentiometer is used to adjust and control the electric potential difference (voltage) ap*plied to some device or part of a circuit* The output voltage may be varied from zero to the value of the input voltage Examples of its use are as a field current control on an electric generator and as a volume control on a radio Since the resistance between the input terminals is fixed (assuming the load device takes little current) potentiometers with precision resistors are used as range selector switches on vacuum tube voltmeters and other precision electronic measuring equipment Other uses are to divide a voltage into two parts to compare two voltages and to divide the total resistance between two parts of a circuit The ratio between output and input voltage as shown in Fig 2 is

$$\frac{e_{out}}{e_{in}} = \frac{r_2}{r_1 + r_2}$$

Construction A potentiometer may be linear or nonlinear In the linear case the resistor is uniform and the voltage distribution along the resistor is the same for any fixed fraction of *its total length* Therefore the output voltage (Fig 1) is proportional to the slider position In a nonlinear potentiometer the resistance per unit length varies and *the output voltage varies as some function* (such as the logarithm the square or the sine) of the slider position Nonlinear potentiometers are often called tapered potentiometers In some cases the current carrying capacity of various parts of the potentiometer may be different

A slide wire potentiometer employs a movable sliding connection on a length of resistance wire

A wire wound potentiometer is similar to a slide wire one *except that the resistance wire is wound* on a form and contact is made by a slider which moves along an edge from turn to turn The form may be straight or bent into a part of a circle in *which case the slider is mounted on an arm* which is rotated by a knob The form may be made of a

era..l material for heat res stance o a good grade (and paper or pla t c (k ow as a card)

A carbon potentiometer u es a thin layer of car bo or graphite i pla e f t nce wire

A butt type potentiometer ses fi d co tact po t hi h are to hed by the slider Fixed re t rs a e the c nected betw en the buttons

Multu n pote t om te s Sold der a us trad names, these have the resistance mater al u lly led r ista ce wire pl ced in the form f a cyl dr al hel A sl de is m d down the h lix by a l d s ew a rangeme t This arrange ment perm t a l ng length f pote t meter in a m ll l me a d g es m re ac te adj tm nt than po bl with a i gle t n pote t meter

Trimme p tent om te Th s is a mall p t tt o rt r sed t p o de a small percentage adj t t a d is often a oc ted w th a se e t ol

[CFC]

Potentiometer (voltage measurement)

A dev for the me ur me t f a electr moti f re (mf) by c mp r n w th a known pote t l d f er (s ELECTRICAL MEASUREME TS Po TENTIAL, ELECTRIC) The k w p te t al d ff r ence i est bl hed by the fl w f a d fi te c rent th gh a k w r i t n us g ta da d ll a a fere Th p i pal p te t met c e (1) the o t t t dc p t nt m ter (h t lly k wn Pogg nd f fi t m th d) ( ) the B ook defl t nal dc p te t met (t t l th ba c t t eu t p te t me t) (3) th t t e t d p te t me t (k P gg d l ond meth d) (4) th Drysd le ac p tent m ter and (5) th Tin sley Gall c p te t m ter

Constant current dc potentiometer Thi s d l u d in th t dard zat f dc m g h rum t tt h e t i ll t te l in F 1 A b tt ry ca a urrent I t fl w thr gh t ll ted l i l de R W tl th w tch S ect d t th ta d d ll d l d a d b set I n app p te al e f r t e R th l d w t I dj ted nt l th g l m t t I q lt Tl l d w e

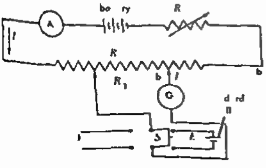


Fig 1 Elementary dc potentiometer (F m l F d Applied El c l M m t Wiley 1935)

oltage $R I$ is n w eq l t the tandard cell emf E

The unknown ltage V is then sub t tuted for the standard c ll a d the sliders a a d b are ag in adjusted f r a null gal a meter read g with l dewire curre t I s unchanged Let the new alue of sl dewire res ta ce be R_2 The unknown voltage is

$$V = E R_2 / R_1 \qquad (1)$$

Thus th s pote t meter compares potential dif ferences i te ms of k own re stances which are s lly cal brated in te ms of volt and m llivolts

A mplete p tentiom ter ci t is h wn in Fig 2 Th re i t ce of the dial switch the ma n l d wire d the ta dard lidew e rep esent R Tr sfer f m the standard zing t the meas ur g cir t is a mpli h d by the switch U W th the switch i the left po it n th tand d cell w th volt ge E and the gal anom ter e c nected acr s the esist ce comp sed f nine coils d pa t f the lid ir Balanc is obt ined by dj tme t f th eg l t ng rheo tat The switch is then th wn t the ght nne t ng the unk own ltag E a d th g l nom ter cro the dial w tch d m i l d w both f wh ch a e d justed to bta bal ce A ra ge witch red ce th l dew e c e t to ½ or ½ f it full al e whe eq ed The me ement nge of the con tant cur t p tent m t r i 0–20 lt Mult plie of 1 0 1 d 0 01 re a l bl Th de ce has d g ne te i fi m t d e r rs can be reduc d t the o de f 0 025% f tl e eadi g P te t m ter me s em nt f ur ent i ace m pl l ed by pa g rr t thro gh a ta d rd z d esi t r f pp pri te l e and m m ri g the po tent l d ff er s th re isto

Brooks deflectional potentiometer This po te t met r el m te th i m c n umi g ope a t o f obt i g a e a t bal n e f the l dewir Thi ac mpl hed by cu try nd gal n m t cal b at by wh h the g l a ometer r ad g m y b dd d t r ubt acted f m an appr x m t d l tt g A ll t ated in Fig 3 E i th k lt g E the te m al ltage of a t g ll f gl gible r s t ce a d R is the t f g l a m te pl it ere re i t r A ly f th c r t h w th t if the q antity $P + R (R + R)/R + R + R$ k pt c n t nt f ll p ti n f th l de s the g l n met r l l b ated d tl in lt Th i h e ed by th dd t n of th aux li ry r to R i w th the g l nom t nd l de A the sl de m ed n em t f t e ΔR i dded t btra ted f m th ab e res tan e t ke p th rat n r t Th t t l unk wn mf is th lg l m f the l d r tt g d gal a m t r ad g Th i t m t th rwi e m l r t t ed d flect al pot nt m t a ailabl i r g f 0 15 lt wh h m y be e ded to 300 lt a d 0–0 5 mp wh h may be xtended

$$\frac{1}{c^2}\frac{\partial^2 W}{\partial t^2} = \nabla^2 W \qquad (20)$$

c being the speed at which disturbances such as waves of sound or light travel (*see* WAVE EQUATION; WAVE MOTION). Then

$$W(P, t) = \frac{1}{4\pi}\oint_S \left[\frac{1}{r}\frac{\partial W^*}{\partial n} - \left(W^* + \frac{r}{c}\frac{\partial W^*}{\partial t^*}\right)\frac{\partial}{\partial n}\left(\frac{1}{r}\right)\right] dA \qquad (21)$$

where S is a closed surface, r is the distance from the point P to dA, and the asterisk indicates that the time t is to be replaced by the earlier time $t - r/c$. This formula, which shows precisely how signals traveling at the speed c propagate to the point P conditions formerly holding upon the surrounding surface S, is said to represent the wave function W in terms of retarded potentials. *See* CALCULUS OF TENSORS; CALCULUS OF VECTORS; POTENTIALS (MATHEMATICS).

Bibliography. W. V. Houston, *Principles of Mathematical Physics*, 2d ed., 1948; O. D. Kellogg, *Foundations of Potential Theory*, reprint, 1953; H. B. Phillips, *Vector Analysis*, 1933; J. A. Schouten, *Ricci Calculus*, 2d ed., 1954.

Potentiometer (variable resistor)

A variable resistance device with three terminals used in electric circuits. As shown schematically in Fig. 1, the three terminals are the two ends of a resistor (or series combination of resistors) and a movable connection which allows adjustment of the resistance between this movable connection and either end connection. The movable connection often consists of a sliding contact which moves along the actual resistor element. The size or rating of a potentiometer is specified by giving its total resistance in ohms and the permissible losses in watts. *See* RESISTOR. By using only the movable and one fixed connection, a potentiometer may be used as a rheostat. *See* RHEOSTAT.

The term potentiometer is also applied to a precision instrument used to measure or compare electrical voltages; for a discussion of this device, which depends on the same type of resistor arrangement, *see* POTENTIOMETER (VOLTAGE MEASUREMENT).

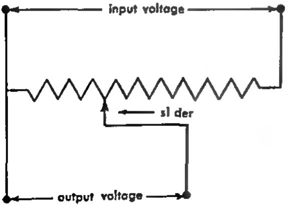


Fig. 1. Potentiometer schematic.

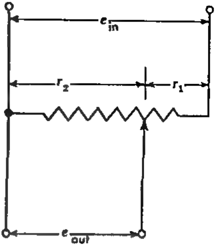


Fig. 2. Voltage divider.

Use. A potentiometer is used to adjust and control the electric potential difference (voltage) applied to some device or part of a circuit. The output voltage may be varied from zero to the value of the input voltage. Examples of its use are as a field current control on an electric generator and as a volume control on a radio. Since the resistance between the input terminals is fixed (assuming the load device takes little current), potentiometers with precision resistors are used as range selector switches on vacuum tube voltmeters and other precision electronic measuring equipment. Other uses are to divide a voltage into two parts, to compare two voltages, and to divide the total resistance between two parts of a circuit. The ratio between output and input voltage as shown in Fig. 2 is

$$\frac{e_{out}}{e_{in}} = \frac{r_2}{r_1 + r_2}$$

Construction. A potentiometer may be linear or nonlinear. In the linear case the resistor is uniform and the voltage distribution along the resistor is the same for any fixed fraction of its total length. Therefore the output voltage (Fig. 1) is proportional to the slider position. In a nonlinear potentiometer the resistance per unit length varies and the output voltage varies as some function (such as the logarithm, the square, or the sine) of the slider position. Nonlinear potentiometers are often called tapered potentiometers. In some cases the current-carrying capacity of various parts of the potentiometer may be different.

A slide-wire potentiometer employs a movable sliding connection on a length of resistance wire.

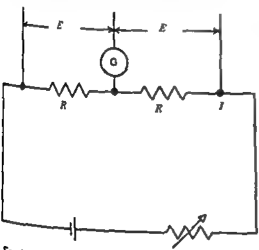
A wire-wound potentiometer is similar to a slide-wire one except that the resistance wire is wound on a form and contact is made by a slider which moves along an edge from turn to turn. The form may be straight or bent into a part of a circle, in which case the slider is mounted on an arm which is rotated by a knob. The form may be made of a

ac su ement M ximum err s of 0 1–0 2% a e ob ed, dep d g pon the a cura y of the am e a d en t ty of the g l a met

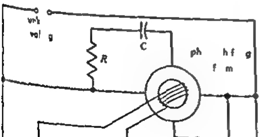
Tinsley-Gall ac polar potentiometer Sh wn n Fg 6 th s p tent ometer mea re the unknown emf b me u eme t of the n ph se nd quadr ture compon ts in refere ce t a st nd d c rent T pt t mete are u ed the r nts in wh h are n me cally equ l b t 90 d spl ced n pha e Th phs pot t m ter is fi t ta da di ed b closing s t h S t the left and dju ti g R f r ll e d g f gal n m te G Th

$$E = I R \qquad (3)$$

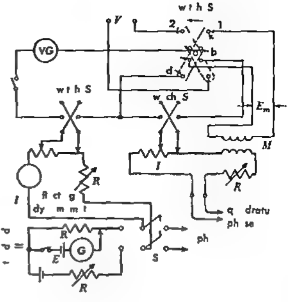
R is pr dj ted o that defin te rr t u ually 50 m'll amperes (ma) fl w th ugh the l d wire The e d ng f the reflect n dy amomete s then served Alte nat c r ent f om th in ph e ance i th appl ed by lo e of w tch S to th right, nd rheost t R i dju ted to ep d e the 50-m re d ng f the refle t n dynamometer



Fg 4 E m t ry t t t p t t m t circu (F m I F K d Appl d El t I M re ts, W ley 1956)



Fg 5 Drysd l po m circu (F m I F Kinnard Applied Ele t ic l Me m t W l y 1956)



Fg 6 T l y G ll a p t t met c t (F om I F K d Appl d El ct l M m t W l y 1956)

The q ad t e p t ti m ter s now sta da d zed by l s e of S in p s t o l t geth w th closur f o tact b d cd Th s se se o n ct the q d t r l d w r thr gh th brat n g l a meter a d the i ph slidewi e t the e o d ry f mut l d ct M i wh ch an mf

$$E_m = j\omega M I \qquad (4)$$

gene ted R ers ng w tches S a d S a n e t d o th t the lt ge dr ps nd e ar pp d The i pha e lidew e s set t a predeterm d al e f d c d lt ge E_m a deter m ed by the f qu n y d ffic nt f mutu l d ct Th heo tat R then djusted f r null d ati n f G nd 50 m w fl w th o gh the q drat sl dewi e The tran fe sw tch S s n w h ged t p t o 2 c tting ut the mutu l in d t d e es c n e ti g the sl dewir swit he S_2 d S s well s th br t gal n m te to th nk wn lt g V The ppa atu i n w re dy f me u em t f the q d t e c mpone ts f th wn olt g All fo r qu drants may b xpl ed by u e f e rs witches S a d S Th te t m te f r best es lts r q es ery tabl c p we supply c n ting f tw gle-ph e altern tors with adj table ta t It i u ed pe i lly f r u h peci l zed l b to y p d r s a in trument t a f rme r t ph e- gl d term nat n a d able test g F th m thod f olt ge meas reme t ee VOLTMETER

[A J C.]

B bl g aphy I F K nna d *Appl d El ctri l Meas m t* 1956

Pottery

V el m d nt ly r p rtly of cl y nd fi ed t t g h d p od t oc a ll the t rm f r t y t the l e g ad of uch ware Alte

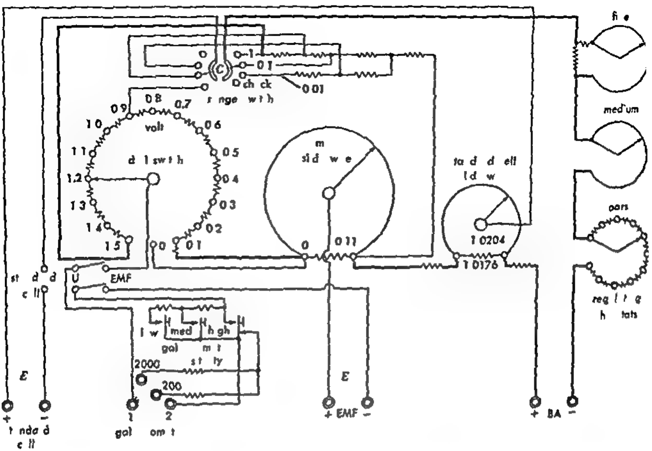


Fig 2 Complete dc pote tiomet r ci cu t (Leeds and Northrup C)

to 150 amp with pecial multipliers Maximum er rors of 0.05% elf contained plus 0.04% for mul tiplier if u ed are obtained

Fg 3 Eleme tary B ooks defl ct o potent omete c c t (From I K o d Appl ed Elect al Mea eme t Wiley 1956)

Constant resistance dc potentiometer Thi in trument i e pecially adapted to the mea ure ment of very low potentials As illu trated in Fig 4 the unknown potential E i applied to the known con tant re i tance R and the current I i adju ted for null reading of the gal an meter In erie with R is another con tant and known re sistance R The pot ntial E acr thi re i tance is measured by any null type potentiometer Then

$$E = E_r R_2 / R \qquad ( )$$

Thus the range of the null type potenti meter may be extended downward many fold by making R large and R_2 small Reliable mea urement in the micro lt range i practical le if care i taken t a oid para itic emf in R The n ll potenti meter may be replaced by a dc oltmeter b it mea ure ment accuracy i thereby dimini h d

Drysdale ac polar potentiometer This i hown in principle in Fig 5 An rdinary lid wire i sup plied with current by a pha e- hifting tran former The amount of current i mea ur d by an ammeter which mu t be an accurate ac to dc tran fer in strument The p tenti meter urrent and oltag drop along the lidewire are br ught into pha with th unknown voltage by adj tm nt of th tran f rmer rot r Th unkn wn ltage i th n mea ured by ol ervati n of the lidewir tti g f r a null indicati n of th ibrati n gal an m t r The potenti meter i calibrated on d rect c rre t by u e of a dc potenti meter Th equi alent alue of ac a m a ured by amm t r A i maintained f r

sr f the egg the ■ son of the ye r the diet and age of the breeding stock a d the le gth of time and onment l co d tio s under wh ch the ha hi g eggs were held before being pla ed in the b t

F rtil ty f eg s ge er lly will ex eed 90% but ma be ad ersely affected if the m le birds are sick b t too m h be ome chilled suffe from fr en combs r ttles or are g neti ally infe ior in breed g q l ty

The season of the ye r ffects hat habil ty of eggs r r less i di ectly Hat h s may b p or th fall hen h ckens n rmally m lt b t a flock f y ng p llet that i ot m lt g w ll pr du e h t h g gg of high q al ty at thi se s ■ Ex es y h t r e ld we ther may d er ely ffe t the hatch g

Age of breed ng stock i a facto n the res lt btained Both the fe t l ty of th egg and the ac tual hatch ng of the fertile g decrea es w th ad an g ge of the to k

Th ■ d ti ns under wh ch eggs ar held p r ■ incub t n a mpo t nt I p i ple eggs should b pl ced und r i cub t on w th n 3 days f r th y are laid but the life of the mbryo m y be m ta d f r p riod of 10–20 days f the eggs st ed pr perly The h lding tempe atu e mu t not e ceed 65 F and the hum d ty of the h ld ng oom ho ld exceed 70% A y u due lo s f mo stu e f m with the egg will b detr me t l Th eggs will al ■ d t be t r ed tw ce d ily f h ld m e than 1 week in order to keep th yolk fr m adhering to the hell membr nes

The d et of the breed g h s mu t be c mpl t in the nu ent facto req ired for th gr wth of the embry The v tam requirement eed p rt c al r tt ntion Hens will p od e egg on a d et q te inad qu te f ■ gr wth nd s ch eggs w ll g l w re ult when nc bated Fi lly the breed ing stock must be free f any d sea e tra sm tted thr gh the egg su h as pull m d e s (s SALMONELLA) F rtun t ly the ad lt sto k affe ted th th d e e may be subje t d t a bl d t t d a r e b rd s moved Oth r di that h the tal ty f the st ck aff ct the hat hi g f th gg w ll a u p a ite both e t nal a d i nal l ■ CESTODA MALLOPHAGA NEMA TODA TREMATODA)

Baby chick industry Foll w ng th hat h ng f th gg th r t l pse f 3–5 d ys when the you g ch k d n t e sly req feed wa ter Th yolk f th egg i d awn d tly into th body ty f th emb yo at bo t th tim the h ll i b k n d th h k p p res t me g Th pr des food f the n w h k f a few d ft h t h g w e p i n f n tu e t t k f th h k d r ad r nd ti M t kes d t g f thi p tecti n per od nd uses th t m t t s port th h k t all p rt f th w ll Th mm l h pp ■ f h k t rted i th ly p t f th tury d ha ed ed t l m ll f h k n w h t hed a d h pped weekly M y f rm n l g h ect with th f b t n f h k th y

imply place their ord rs and rece e tl e chicks when th y want them Th s development has made it po ible for b eeding operati ns to be more cen t ali ed with c sequ nt mpro ement in the grade of chicks p oduced In addition it ha esulted in the growth of large farms requi ing thot and of ch cks t one t me n impo sibility wh n th fa mer had to dep nd o hi own breeding flock to ecure h s upply of hatch ng eggs Without the hatch ry to produce chi ks as needed the com me ci l poultry i d stry as t exi t today would be unknown

Brooding The b ■ ding of chi ks under art fi al c nd ti ns date ■ ck to th late 1800s whe al and o l bu n ng sto es w re u ed to furnish he t for brooding p rp es M ny f the e to e ha e not ch nged mu h i de i f r more than 50 years which s gge ts that little ad an ■ has been m de in the ci n e f br odi Electric and gas bur i t e ha e b en dev l ped s well a l rg entral h at ng ystems which use eith r h t wa ter or h t ■ but the br odi g of chi ks n l rg nit ha n t been t ■ s cces f l bec u e of d s s e hazards B tter ■ of wire ages ha e at times been u ed but the e al ha e n t been too s ■ ful e ept f p ment l gr ups wh re sm ll umbers r kept Although s me fa m may bro d e e al h ndred tho s nd hicks at one time the e h k u ually r tart d in mall g oups of 300–500 e h

The temperat re requirement f r baby chi ks is 90 F for the fi st week fte which the t mpe a ture may be redu ed 5 degre s we kly until the chi k are 6 we k ld At that ag they h ld be well feathered a d able to withsta d moderate tem per tur s ab fr ezing p o id ng they are pro t ted f om w nd and in

In the brood ng of ch cks hum ■ judgment is nece sary in daily ca e f the stock In climates o e s n whe e there a e wide vari tions in day a d night t mpe atu s the car tak r mu t a sume m re spon b lity f r the care nd management f th h ck N me h n c l d i e c n meet the ituat O rerowding e h at ng or ch ll ng n f r a few hou a ha ■ ery seri us ults

Beca h ck pick t anyth g n ght f r the fi t few days afte the hat h, the litte ■ ed t the flo m t b m th g that will not be i juri u Sa d has pr ed u e ful l ut other mat l s h cut traw wood sh ing pe t m s o t hull peanut hell o mo t ny nonp i o but mo tu b rbe t product m y b u ed p d d it co e d for the first few day w th pap t ■ nt th chicks f om eating it. The pap n t r may serve a a place t feed the h k f the fi t 5 day or unt l th y l arn whe the r gular f ed hoppers l ted Water l is a p bl m f r the fir t few days b c u th h k mu t l arn where th wat r is l ted In g e al the p cti e i to ha e 2 or 3 mall con ta f r h g oup f ch k unt l they l arn th locati n f th perm ent wat r supply

Diet F r the fi t f w w k of th r l e b by h k ho ld be g en a d et th t i ■ mplete i

natively it refers to the manufacturing plant at which such ware is made. An older meaning is the art of making such ware; in this use it becomes synonymous with the older definition of ceramics (*see* CERAMIC TECHNOLOGY). Pottery may be glazed or unglazed (*see* GLAZING).

Grades of pottery are distinguished by their color, strength, absorption (the weight of water soaked up when the piece is submerged, expressed as a percentage of the original weight), and translucency (ability to pass light). All these properties refer to the material or "body" under any glaze present. *See* PORCELAIN.

China is white in color, strong, has less than 2% absorption, is always glazed, and is translucent in thin ware. Special types are bone china, containing phosphates from calcined bones as a fluxing material; hotel china, made extra thick for maximum strength and therefore not translucent; frit china (also called frit porcelain), containing ground glass to give a translucent body maturing at a moderate firing temperature.

Stoneware has a cream or brown color, high strength, 0–5% absorption, and no translucency; it is often unglazed. Chemical ware is an example.

Earthenware (sometimes known as semivitreous china) is white or ivory, has less strength than china or porcelain, 3–10% absorption, and no translucency; it is usually glazed. Most everyday tableware is of this type. Faience is a special type with a soft porous red or yellow body covered by an opaque glaze. Majolica ware is a type having over 15% absorption and an opaque glaze over a relatively weak red or gray body.

Other special types of pottery are Parian ware, a body with a high flux content, usually unglazed, which fires to a smooth marblelike finish, and terra cotta, a yellow, red, or brown earthenware with no glaze, used for art sculpture and similar purposes.

The firing of glazed ware is usually done in two steps: first the unglazed body is fired to give it strength, and then after the glaze is applied it is refired at a lower temperature (except porcelains, where the second firing is at a higher temperature).

Absorption is determined by the presence of open pores or voids in the fired material into which water can penetrate; in general, the higher the firing temperature, the lower the absorption. Body color is determined mainly by raw material purity. Strength depends on the porosity and also on the amount and type of glass and crystals developed in the body on firing. Translucency is obtained in products in which there is low porosity and little difference in index of refraction between the glass and crystals in the body. *See* CLAY. [M.C.M.]

Poultry production

The production of poultry embraces all phases in the life cycle of chickens, turkeys, ducks, and geese, but does not include game and other wild birds. The life cycle includes the incubation of the eggs, the growing of the stock for either meat or egg production, the egg-laying phase, and the breeding stage when fertile eggs are produced for incubation. The subject will be discussed with particu[lar] reference to chickens, followed by a general disc[us]sion of turkeys, ducks, and geese.

Incubation. The practice of hatching eggs [by] artificial means rather than by the use of the h[en] dates back to the days of ancient Egypt. As a [sci]ence it has been developed primarily since [the] start of the twentieth century. The modern incu[ba]tor is a scientific piece of equipment designed [to] give the developing embryo an ideal environme[nt] with automatic control of temperature and humi[d]ity, and to include labor-saving and safety-cont[rol] devices.

The temperature required for incubation [is] 99.75°F. Variations of a degree or more from th[e] optimum level will delay or advance the number [of] hours required for the chick to hatch. Uniform[ity] of temperature is important to maintain a hatc[h]ing schedule with eggs to go into the incubator [at] a specified time and the resulting chicks to be re[-]moved and shipped also at a prescribed tim[e]. Forced circulation of air around the eggs by th[e] use of fans ensures an even distribution of th[e] heat whether it be from electric coils, hot wat[er] pipes, or other sources. Thermostatic contro[ls] maintain the desired temperature.

Next in importance to heat control comes humi[d]ity regulation, the purpose of which is to conserve the moisture within the eggs yet permit some evap[-]oration. Otherwise the embryo may drown. *See* EG[G] (FOWL). The requirements are not so exacting a[s] those for temperature; a 60% relative humidity [is] satisfactory until the time of actual hatching, whe[n] it should be raised to [7]0%.

Providing ventilation to an incubator, thereby en[s]uring sufficient oxygen, is still a matter of judg[-]ment rather than scientific control. Most incubator[s] have a manual control which is set to give sufficien[t] ventilation when the machines are located in [a] warm, well-ventilated room. The room itself mu[st] receive serious consideration and be designed t[o] maintain uniform conditions regardless of outside weather changes. Ventilation within the incubator [is] of greatest importance when the chicks ar[e] hatching and for a few hours following the hatch when they are drying off. Suffocation may easily occur with inadequate ventilation at this time. Because of the special requirements when the chick[s] are actually hatching, most incubators are designed to operate in two sections, one to hold the eggs f[or] the first 18 days and the other a strictly a hatch[-]ing compartment.

It is necessary to turn the eggs every 4 or [5] hours until the embryos are about ready to hatch. This prevents the embryo from adhering to the shell membranes. Automatic devices are timed to take care of this chore. Other than to see that the equipment is functioning properly, an incubator does not require any measure of human control from the time the eggs are set until the eighteenth day of incubation.

The normal hatching expectancy is 80–90 chi[cks] from each 100 eggs set. The number varies with efficiency of operation of the incubator, the fertil[ity]

mts a m h t supplement grain m st be more conce trated t the f tors th therwise would be nece ry Comm rcial eg p ducti n is becom ng more a d mo e a pec al ty and th u e f b grown gr in is fast l ing its popularity As nd ted in th e f i cubat n nd the gr g of h ks the farmer o l nger needs t h th techn cal knowled t feed a flock of lay gh ds p perly He mu t se th t the mach ne y f cuo s l a ing the m re t hn cal problem t t hat h ryman a d th feed dealer

Health D s es of p ultry h plagued the in d try at ll t mes d till present a problem but the empha is i w di ected t ward pre ent n of E se a d ma nte ance of he lth rather than obta ning a cure for sp cific d e An dult hen d t t p f rm econom ally as a p duc r of eggs m st be he lthy i di d al She m st b raised free of para ite a d n t be ret rded in growth b d e xp u e to di ea e Mortality in young stock ha been bro ght fa ly w ll under co trol by the rt l el m n of pull um disease thr gh bl od te ting f the p nt stock u l thr t keep coc di s der ont ol vac na ti f N e tle d laryngot a heiti and f l pox nd f ed g tib ot s t gi e g ater resistance t other i fection (s e ANTIBIOTIC Coc cidiosis NEWCASTLE DISEASE) P ie may b kept under co t l by the judi iou u e f d ugs and chem als at the p per t me pl d w th m age ment pra t es th t aid n keep ng the dence f h t n t a l w l vel B eed f health a d k m rt l ty ha t ken n ew gn fi nce and e of h k s e v lable that ha e d mon st a d res t e t d e Th re a e ome d seases t ll to be i e t gat d hiefly tho e dealing th h t termed the le kem a omplex r leukosis es lt ng in paralys a d t t l di abil ty

Environmental problems Th ff t f the en ent th h h f ch ke in need t b e h bee e it incl d th p blems f tr ll g th h u s and i t n ty of light the te per tu hum d ty entil t a d flo p ce t they affect he lth d egg p od t n D ns ty of th pop l t a ther f ct r Light ha b en bjet f d able t dy a d gg p d c k n t be r tarded f chick e b- t les th h ur f light d ly H w g tock doe n t h w m l p n e in n e h p t g th t Optim m temperat re ly gg p od i n h s n t b en e t bl hed b t chicken eem q te adju t ble n th espect and t perf rm t f i r ly i a w d range f t ther be ome clim t d Hum d t d ent l t n r qui ement ar t ll highly l l th g n al r a f kno l dge n gent need f inf rm t n reg d g the f l z f th f wl whi h mu t be und tood b th al effect f the v nm t a be t e determ ed

Heredity Alth ugh ese h h s d ne mu h to k ledg f th trit n l eed f the h e d h perm tted th nt l f many d seas the gen tic const tuti n f a fowl is highly imp rta t s well Fortun tely genetic st ha e been w rk g in this field a d the re now chickens that can grow rapidly and produce eggs at high rates when they are p perly fed and man ag d The ro ing of br eds ha result d in m rked imp ovem nt n the d v lopment f broil rs and meat chickens The d minance of ce ta n desirable tr uch a the inheritance of l er pl mag h en bl d the b oiler gr we to u e m les with th cl ara ter tic to prod p ing with l ght c l red fe thers desired by the ma ket Sex of the chi ks may be dete min d by th c lor f the down wh n the hicks hat h r by other marking and the se ing of chick by phy ic l e amination has eplac d the p acti e of us d ffer t b eed to take advantage of k own inh rit d ex diff rences

Inh rit nce of egg prod ctio q al t es has pr ed to be a compl cat d p oblem St rt g o in lly with the use of m les ped greed fr m h gh p duct on h ns many fl ck o e the p st 40 ye h e b en b ought to le el f p duct on angin f om 200–225 egg per b rd per year Cons d ring that p od ct on the farm flocks o ginally w ab t 150 eggs p r b l the ad h s bee well w rth wh le H we a plateau of egg pr ducti n de el ped w th in str ins after the us f ed greed m l o e se e l ge e ation and t wa not unt l st ain were r ss d th t fu th r mp ement took place Intensi inb eeding f diff rent strains w thin th bre d follow d by oss g l as br ught about n i c i product on up to level exceed i g 250 egg pe bird Th trend has had a tend y to place the b eed g op rati s n the h nd of rel ti ely few ndi id als or mpa ie b c se s many b d m t be k pt a d t ted f r thei bility t how mpro eme t when cros d th t it is n exp e ope tion The actu l f rm ope t r of th fut re w ll dep d e ti ly on an de ga izat on to b eed the typ of ch ke s d ed a d he will b re p n ble for only the ph s al re of th tock

Marketing The dve t f the chain t e v t m in m handisi brought w th it a d m d f r large q t ties of poultry pr d ct f un form de a d q al ty Th were difficult to obta n whe ach f m r f llow d h w lin tion As a e ult po lt y p du t are bei g p d c d a d ma ted nde wh t termed integration a system wh eby the p d e g e t m ket h p duct th gh a prescribed ch l w th ch cks fr m a d finit urce and fed a d et de gned t g e the be t q ality In ome insta ces c pera ti asso at s a erv g th me pu p a d g e the farm n l m nt f e tr l Th ind d ual produ e d g t m k t pr d ct th ugh pr ate cha el r th th a t grat d sy tem m t keep the q l ty f h p od ct at a pe k level th rw the tl t w ll be gr atly e t i ted I p t l r gg q l ty eeds to be t ed bec u f h e l t r p dly u l ss egg k pt d f g at n f m th t me th y r laid until they re h th umer

Nutrient requirements for chickens in percentage or amount per pound of feed

	Starting chickens 0–8 weeks	Growing chickens 8–18 weeks	Laying hens	Breeding hens
Total protein, %	0	16	15	15
Vitamins				
Vitamin A activity, USP units	1 00	1 00	000	000
Vitamin D, ICU	90	90	5	5
Thiamine, mg	0.8	?	?	?
Riboflavin, mg	1.3	0.8	1.0	1.7
Pantothenic acid, mg	4	4	1	4
Niacin, mg	1	?	?	?
Pyridoxine, mg	1.3	?	1.3	1.3
Biotin, mg	0.04	?	?	?
Choline, mg	600	?	?	?
Folic acid, mg	0 5	?	0.11	0.16
Minerals				
Calcium, %	1.0	1.0	5	5
Phosphorus, %	0.6	0.6	0.6	0.6
Salt, %	0.5	0.5	0.5	0.5
Potassium, %	0.[illegible]	0.16	?	?
Manganese, mg	5	?	?	15
Iodine, mg	0.5	0	0.2	0.5
Magnesium, mg	2 0	?	?	?

Source: Natl. Acad. Sci.–Natl. Research Council, Nutrient Requirements of Poultry, Publ. 301, January 1954. USP, U.S. Pharmacopoeia; ICU, International Chick Units.

all the needed proteins, minerals and vitamins. The requirements in this respect have been fairly well established, more research having been done on the diet of baby chicks than on any other phase of the poultry business. The recommended allowances for the various components of the diet are shown in the table. Feed ingredients which supply the needed nutrients when mixed together in a ground form are known as mash and this is fed to the chicks as soon as possible after they are hatched. The amount of feed is not limited in any manner. Along with it the chicks are fed a hard insoluble grit such as granite on the supposition that it aids in the utilization of the mash. Proof of this is not definite, however. Sometimes the mash is compressed into pellet form and fed in that manner or the pellets may be reground to a crumbly consistency. The object in producing the pellet or its crumbly form is to improve the physical condition of the feed and thus to encourage a greater intake. Some feeding materials that in themselves are not palatable to chicks may be used to advantage if prepared in pellet form.

Before sufficient knowledge had been gained to mix a complete feed for chicks the practice was to have chicks get out in the sunshine with a supply of grass available. Milk was used instead of water and grains were fed in place of mash. Today research specialists in both the agricultural experiment stations and the feed industry ensure delivery of just what the chicks require for rapid growth and good health. The farmer's obligation is to see that the feed is placed before the chicks. Even that is purely mechanical because the feed is delivered in bulk and is stored in bins from which it moves directly into automatic feeders that run throughout the poultry house. Science has made it possible for one man to take care of [illegible]0 000 or more chicks because the operations are mostly mechanical. Before all this could come about the nutritive requirements had to be known so that the feeding could be as accurate and simplified as is now possible.

For young chickens to be sold for broiling or frying purposes the diet remains the same as used for baby chicks. However, if the purpose in rearing is to produce pullets that are to be used later for egg production the diet is changed at about the age of 8 weeks. Growth in chickens tends to divide itself into two periods. The first consists of a constantly increasing rate of gain in weight week by week, the second by a constantly decreasing rate of gain in weight week by week. In chickens the break between the two periods comes at the age of about 8 weeks, although diet, temperature, breeding and disease will tend to alter this to some extent. Therefore, starting at the age of 8 weeks, growing pullets are fed diets that are lower in protein as well as some of the other nutrients as indicated in the table. Under practical field conditions the changes are more radical than indicated in the table because vitamin D is not needed in the feed when the chickens have access to direct sunshine. Also some of the other vitamin requirements may be met by having the young pullets on a good green range and the diet may be altered accordingly. When the stock is being reared indoors or at a season when range facilities are unsatisfactory the feed must be complete or the pullets will become unhealthy and growth will be stunted.

Egg production The period of egg production is marked by a normal increase in the rate of lay from the time the first eggs are produced until the flock reaches a peak of 70–80% production, that is 70–80 eggs from 100 pullets daily. This level generally is reached by the time the pullets are 8 months old. The production level will then gradually decline and the peak will never again be reached in the life of the bird. Usually a complete feather molt occurs after egg production has continued for a year and during this molting period the rate of lay may be as low as 10%. After new feathers have been grown egg laying is resumed for another year. This process is repeated year after year during the lifetime of the fowl with a gradual decline in rate of egg production each succeeding year.

Several factors have effect on the egg laying behavior of a flock of chickens. These include diet, environmental conditions, health and genetic constitution (see GENETICS).

After a suitable mixture of feeding materials has been established to meet the requirements the resulting feed is fed in either mash, pellet or crumble form as indicated for chicks, usually by the use of automatic feeders. On farms where grain is grown a portion of the diet may be supplied as whole grain and thus the cost of the feed is reduced. Because grains are primarily a source of energy and are deficient in protein, mineral and vi

ems, a ma h t pplem nt grai must be more co entrated n these fact rs th n therwi w uld be neces ary Comm ci l egg prod ct n i be om ng m re and m re a peciality and the u e of h grown grains i f t lo i g its popularity A md ted in the s e of nc b t n and the growing of hi ks th f rm n longer needs t ha th tech al k wledge to feed a flock of lay ng bird p perl He mu t ee that the mach nery functi lea i th mo techn cal problems to d h tcherym a and the feed d ale

Health. D eases f po ltry ha pl gued the in d try at all t mes and t ll p ent pr blem but the empha w d rected tow d p eve tion of d e and maintenance of health, rath r than ob taining cure f pec fic di ease An ad lt hen that t perf rm eco m lly s producer of gg m t b h althy individ l She m t be reared free f para tes a d n t be retarded in growth by d e po e to di e Mort l ty in young tock h been b ought f rly w ll unde control by the irt l l mi at n of p llorum d th u h blood test of the p e t tock u e f drug to keep oc d os der co tr l v e a to fo N a tle di se l ryn t heiti d fow pox, d feed ng a t biot e to g e greater re sista t othe fect us (e ANTIBIOTIC COC CI A NEWCASTLE DISEASE) Para ites may be kept under c tr l by the j d us e f drugs d heir als at the p per time coupled with m nage ment p a ti es th t d keep th i cide of m estat t f w level Breed g f r h lth and lo m rtality h t ken new ign fi e d strain f hi ken are a a labl that ha dem strated es e t d a The e are me d s ea es still to b in est ted chiefly tho de l g with h t s termed th le k m e mplex r leucos s, res lting in par ly d t t l d b l ty

Environmental problems Th ffect f th en ron ent o the beha r f ch k eed f much sea. h, b n e it incl des th p blems l troll g the h s nd int ty of l ght, th temperat h m d ty e tilat and floor p ce u they ff t h alth and p od t Den ty f th pop l t n i oth fa t r Light has b n th bject f n d bl st dy a d e p od c tion is k own t b r t ded if hi k n b jected to les than 12 h f l ht d ly H wev r p g tock does i h w a im l espon e n f gg pr d ti h t been est bl hed b t a l t pe f rm t f t rily w d a ge f temp t ft th y b m l mated H m d ity and entil t requ me ts e t ll h ghly al. In th gen l i l k wled the g t n d f f rm t rd g th h th re l ff t f the nm t n be properly determ ed

Heredity Alth gh es h h d much t k ledge f th n trit l need f th ea e the genetic c titutio of a fowl i highly import nt as well Fort nately ge eti st ha e been w rk ng in thi field nd th re are n w chicken th t can grow rapidly and p od ce eggs at h gh rates wh n they are pr perl fed and man aged The cros g f b eed ha res lted in marked impro ment in the devel pme t f b il rs a d m at chickens The d mi ance of certain des able tr it uch as the inher tanc f l er plumage li enabled the broiler gr wer t use m les w th th ch ract ri t t prod ce off pr ng with light l red feather des red by th m rket Sex of the hicks may be d term ned by the c l r f th down when the ch ck hatch o by ther markings and the se ing of ch ck by phy ical e ami ati n has repl ed the p tice of u ing d ff rent breeds to tak adv tage of k wn nher ted e d fferen es

I heritance of egg prod ction qu l ties has p o ed t be mpl ated pr blem Starting r g ally w th the u e f m les pedig eed f om high prod tion h n many flock er th pa t 40 y ar ha been brought to levels of prod cti ra g ng from 00–25 egg per b rd per y r Con der g that p od cti n n th farm flock orig all wa abo t 150 gg per b rd th ad e h been well worth while Howe er a platea f egg prod tion devel ped with tra afte the use f ped greed m les o r several ge erati n and t wa n t u t l t i w re ed th t fu ther impr ement took pl ce Int n i e breedi g of diff rent tr ns w th n th breed f ll wed by cro g has br ught abo t a inc e in p oducti n p to lev l e ceed ng 250 eggs pe b rd This t nd ha h d a te d ncy to place th breed g pe t in the hands of rel t ely few ndi idu l e mpa es be au e many b d mu t be kept a d tested f th r ability t sh w mpr em nt when cro ed th t t an expen per t n. The t l farm p rat f th future w ll dep d tir ly on an out de rgan t n to b eed the type f h k de ed nd he w ll be respon ble f r onl the ph cal ca f the stock.

Marketing The ad ent f the cha n tore system in mer h ndi ing b ht with it a dem nd fo l g qu ntit es f po ltry p od ct of n f rm gr de nd qu l ty These we e difficult to btain wh h f rm f ll wed h s own in lin t n A a esult p ltry p od b p oduced nd mark ted unde wh i termed " teg at on " a sys tem wh eby the prod cer ag ees t m k t his product th gh pres r bed ha n l with h ks fr m d finit nd fed d t des gned t th b t n q lity In m n t n es cooper a t rv th m purpo e nd e th farm n l m nt f ntr l Th ind d u l p od des ng t m ket p odu t thr ugh at h nn l th than an integrated sy tem m t k p th q l ty f his p od t t pe k lev l th rw the utl ts will be gr tly e tri ted I part ul g q l ty need to be t es d bec f eshne l st r p dly unless e kept nder r f g t on f m the t me they l d u t l they e b th con m

Economics Science has made the production of poultry and eggs a relatively simple matter in o far as the farmer or actual producer is concerned Large scale operations with thousand of birds now exist and under improving management the cost of production per unit of output is being brought lower and lower This advantage in turn is pas ed on to the consumer who purcha es poultry products in competition with other foods of equal nutritive value With the price advantage in favor of poultry products the outlook for the future eems good

Turkeys ducks and geese The general principles underlying the care of chickens apply equally well to turkeys duck and gee e even though the cientific requirements for the e other species have not been o thoroughly determined However re earch in nutrition and di ea e control is progressing rapidly with some attention being given to genetics Because turkeys ducks and geese are reared for the production of meat they come into direct price competition with broilers and other meat products of the chicken In due cour e and with sufficient re earch there is every rea on to believe that many of the advantages now enjoyed by the producer of chicken will be equally available to the farmer intere ted in turkeys ducks or geese and that these pecies will be a commercialized as the chicken *See* CHICKEN DUCK GOOSE TURKEY *see also* EGG PROCESSING EMBRYOLOGY OVUM REPRODUCTION ANIMAL

[C S PL]

Bibliography See AGRICULTURAL SCIENCE (ANIMAL)

Pound

A unit of ma s in the English absolute sy tem of units al o *a unit of force in the Engli h gravitational system The British standard of mass is the* British Imperial Pound of which a standard is pre erved by the government The United States standard mass is the avoirdupois pound defined as the gravitational attraction or weight of 1/2 204622 kilogram

A one pound force is the weight of the Briti h Imperial Pound at a tandard location that is at any point where the accelerati n of gravity is 32 1/4 ft/ ec In term of Newton s econd law there is a derived unit of ma the slug which is that ma s to which a force equal to the tandard pound will impart 1 ft/ ec acceleration A one pound force is equal to 4 4182 newton and produces an acceleration of 3 174 ft ec when acting on a one pound ma s *See* FORCE MA S MEASURE UNIT SYSTEMS OF WEIGHT [L N]

Poundal

A unit of force in the Briti h al olute sy tem of unit One poundal i the force which will impart to the Briti h Imperial Pound ma an accelerati n of 1 ft ec The foot i 1/3 of the Imperial Standard Yard One poundal i 0 138 newt n *See* FORCE [C E P]

Pour point

The lowest temperature at which an oil will pour when cooled under pre cribed te t condition Becau e petroleum oil are complex mixtures which become pla tic olid when cooled everal olidification temperature are u ed each defined by a definite test procedure The cloud point i the temperature at which a olid pha e eparate from olution For a grease the dropping point i the temperature at which the pla tic olid becomes sufficiently fluid to flow through an orifice For waxes the melting point is the temperature at which the material becomes fluid enough to drop from the te t thermometer the congealing point is the temperature at which a ample wetting the thermometer appear to congeal and hence rotate with the thermometer *See* OIL ANALYSI [M O]

Powder metallurgy

A process of the metallurgy indu try involved with the production of finely comminuted metal powder and of metal objects directly from the powder

The products are u ually fini hed part uch a gears or cams The technique empl yed c n i t es entially of ub jecting the metal pow der t pre sure and heat The heat treatment called intering is performed at ome temperature below the fu i n point of the main con tituent of the product In tead of pure metal p wders alloy powders may be u ed ingly or as mixture Al o *metal powders* may be u ed in mixtures with metallic compound or nonmetallic components Powder metallurgy thus permits the production of metallic or metal like bodies of many shapes without the u e of orthodox metallurgy practices uch as melting and casting

Industrial applications Since many refractory metals have such high melting points that con entional melting and casting is difficult powder metallurgy is the ideal method of producing such products as tung ten for filaments Metal combination in which the characteri tics of each con tituent are retained are of partic lar intere t for certain elec tri al applicati n and they can be produced by powder metallurgy method F r in tance heavy duty electri al contacts and welding electr de c mbine a keleton of refract ry metal hig ly re i tant t abra i n and arcing with a sec nd metal of low melting point and high c nductivity All y ing between the con tituent i negligi l so that the original propertie of the indi idual metal ar pre erved

Ot er examp les are t e manufact re of cem nted carl ide high speed cutting tool cermet and di per i n alloys C rm t con i t of a pred minant n nmetalli or ceramic c n tituent an l a metall c l inder pha e Di per i n all ys ntain minute n n metallic particles di per ed in a metalli matrix They f nd important applicati n in nu l ar r a t r component such a fu l el m nt wl l c n i t f c ml inati n of ura ium oxi le an l l in l m tal

Fig 1 Assort t l t ct l p wd m t ll gy p ts f o pl h p (M t l P wd l d st Fed at)

and co t l r m derat r elements, which c nta Le di pe f bor n and the tr captur g l m nts n al minum star less st l or z rco n trus met l S CERMET

Of g t te est i the production of mall m tal pa h a ge c m a d oth mpo ts f a hines a d i t ument requ r g clo ely con ro ed dime a d p ope t The e parts can often be p od ed at lower cost by powde metall than by oth meth d f h ping m t als The parts ma be teel b s ll y of n pp n ck l, o ch m um

The dev l pm t f metall bod of cl ly controlled p r ty h s m de p ble so- lled self L b a n bro and iro b e beari gs wl ich a t u lly impregn ted w th o l a d used i pl es h h a ma es ble to ter l l br ca tr p met l is al used effecti ely in o l pump gears, m tal filt s nd d aphragms

Fig. 2 P tool d ct f b fh t d m part sho f 9 d Tool l d ppe punch f fil d (te) l w p n h (ght) d core rod (ght) Th th i filt t bl k lower te) re mp ct d w th th m t l Met l P d l d st F d t)

Current collector brushes in electric l machinery are laminated metal powder pr duct C pper lead beari gs who e c n tituent are n t mi ible in the liq uid or s l d tate are typical of metal powder al l ys f un ual mp tions Other appli ati ns of metal p wder include dental all ys chemical reagents cat ly t explo i es and pyrotech ic lder b azi g agent c ating cement addit es pigme t a d flame c tting agent

Powder sources production characteristics Vi tually all metals a d metalloid d many of th r all y and c mp und are a ailabl in pow der f m They may be bta ed from re alt a d othe omp i ds f m bulk metals and al l y The method of prod ct may l e ls fied i to mechan cal phy cal chemical d el ctr al proces es They i clude cru l ng milling ma hin ing graining at m ng conden ation reduct n p ecip tati d pla eme t elect odepo t n dif fi i n all ying nd all y di i tegratio The char acte tic f the p wd rs depend t gr at e tent upon the spec fic manufacturing proc s The size of the i di dual part cles can be made to ary o er a wide rang f m granul s of ¼ in and oa d wn to ne r lloid l i pe hap less than l m ron in d mete Co com tant with a de crea e i s the cum lati e surfac are of the pa t les i cre es pidly to ery large dime s ons This has an ext mel important bear g o the properties f the p wder it beha io during proce ng i to l d bod e and the ultim te p op ert of the e prod ts An ther fact r affe ting the p ce g beha i r and fi al pr pe t s i the sh pe of the di id al p ticles This too dep nds on the method f p duc ng the powde Part cles of mechanic lly commi ted p wders a gene lly sol d in truct re gul in f m and may be eq xed elong ted o flaked n shap Part cl of phys lly p oduced p wder are l o generally s l d in tru t but m tly spheroidal shape Pa t le f chem cally prod ced p wders are al way po ou often ry l ght and fluff a d ally o s t of mult t de f i d d al cryst ll t Ele t l tic powde part l a y n hap and size depend g o the p e u ed Fus d lt ele trol y i p d ce part l embl ng tho obt ned by the hem al p ces es be a they requ e chem l aft tre tm t fo m l of alt re i d d f red t n Aqueou ol t le t oly si p duce the ol d angul m n ry t ll p rt le ult f m the mecha al mmi u t of b ttle c th de depo t or le fy de d itic gg eg t f y tall t f m di t l i lytic depo t

Some m tal powde h pr d d by nl n f th e meth d l m t th p pe t es t th l a t th t m thod Most d t lly im p ta t m t l a be p oduced in powd r f rm by m tha o e meth d th p m tt g select n of th p wde w th th m t u t bl h cte t cs f th p c fic end p d ct Bra p wder e p oduced x l ly by t m t n b t c pp

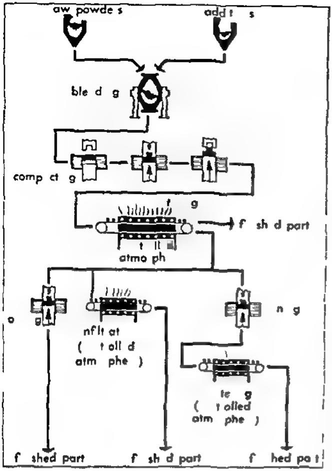


Fig 3 Flow cha t fo fab cat o of pa ts by powder met llurgy (M tal Powder I d st es F de at o)

powders are produced by chemical precipitation reduction and electrolysis Stainle steel powders can be produced effectively only by chemical disintegration of a specially prepared heet metal but iron powder can be produced by at mization reaction with olid or ga eous redu ing agents electrolysis or decompo ition of iron carb nyl

Powder conditioning and processing technique The powdered raw material are cleaned dry stored and te ted Usually they are mixed with lubricating agents to facilitate pressing Very brittle metal or compound powders require careful admixing of organic binder to improve coherency during and after compaction Powders for alloys r compo ite structures are prepared by blending de sired proportion of the ingredient Th blending operation i carried out under variou conditions and usually with dry powder Often blending i c mbined with ball milling Precauti ns m t be taken to pre ent contamination deteriorati n or ignition of the powder during torage handling or blending

Mo t commonly the powd r are pres ed t f rm coherent ma es and the resulting compact are sintered The pre ing operation is generally carried out at ambient but ometimes elevated t m peratures The powders are confined in cl ed dies and heavy hydraulic or quick acting mechanical tableting pre e pr ide the compacting f rce

Rolling of powders into trips i another method of compaction In pecial ca e such as the manufacture of porou filter compre ion of the powder prior to sintering i omitted entirely Mold that allow for hrinkage are u ed either before or during sintering to impart the de ired hape to the powder ma When pre ing i done at ufficiently elevated temperature the intering operation take place under pre ure The application of heat during or after the compre sion of the powder produce a tructure with phy ical propertie compara ble to tho e of similar material obtained by fu i n The sintered tructure however po e es a fine porosity which has an adver e effect mainly on ductility The poro ity re ults from incomplete den ification during compre ion and from gas evolution during heating It cannot be completely eliminated by the sintering phenomena of diffu ion recrystallization grain growth and hrinkage

Although the propertie of the object after intering are frequently adequate for the fini hed product it is ometime nece ary to improve them by further operation such a additional cold or hot compre sion metal working heat treatment or the impregnation of the pores with a lower melting metal Certain other fini hing teps may al o be required including machining plating buffing sanding grinding or barrel tumbling A number of applications require joining operation Brazing oldering or welding of the e part onto other metal base is common practice in the hard metal and refractory metal indu tries Fini hing and joining operati n mu t frequently be adapted to the pecific properties f the e articles Thu care mu t be taken in ma hining becau e of the poro ity Plating method mu t be adju ted to prevent corrosion cau ed by the poro ity and special fluxes or inert or reducing ga eou media mu t be u ed t prevent exce ive oxidati n during brazing and welding at high temperature

Critical evaluation A comparison of powder metallurgy with more orth dox metallurgical method reveal the ad antage and limitati n of this method Th may well serve a a guide for the engineer and manufacturer confronted with the problem of ele ting the mo t uitable producti n method for a particular job

Powder metallurgy d e not make up a prep n derant egment of the metallurgi al in lu tries In spite of the a elerated growth f it different branche powder m tallurgy ha remained a limited and pecialized field The rea on f r th are both economic and technical in nature I wdered tarting material with the ex epti n f m t ir n powd r are m re expen i than th r raw mate rial Tool and dies mu t be d rable an i u lly return their c t nly when many tho s an l of th same part ar produ ed Special tool are r quired for the f rming f mplex hapes beca th powd r d e n t fl w r adily i to lat ral pr tru n I wder of high pecif c lum r quire l ng c mpres i n str ke which in t rn impo e l w

prod ction r te Also the l rge su f ces of the po d rs a e pro e t exce s e ga ls rption leading t b ittl ne of th end pr duct

Yet powd r m tall rgy d e hav a p tential f r further expa on and de elopment of n w appl c tio s. Beryll um p odu t are made exclu i ely l y powd met ll rgy Add ti n l and perl ap p c ta ul r d a ces m y l e expected in the lectr n es, nu le and ocket field where po de metal l gy d per n all ys refract ry metal and metal c ami s with unusu al p ope t e ar l e ng dev l ped. *S* METALLURGY SINTERING [C G G O]

B bliog aphy C. G G etzel *Tr atise o P s d M tall rgy* 3 l 1949-19 ?

Power

Th t me rate f do g work Lik w rk powe is a sc l r quant ty th t i a qu ntity wh ch ha mag n tude b t n di ct n Som u it ften u ed f th me eme t of p wer are the watt (1 j ul of rk pe m nd) nd the ho p er (550 f t p d l w rk p r nd) *S* HORSEPOWER WATT W RK

Usefulness of the concept P wer a n ept wh h e l e u d to d crib e the ope ati n f a y stem o d ce whi h a fl w f en rgy oc rr In many p oblems f apparatu d gn th p w r r ther than the total wo k t b d ne determ es the *e l the* compon nt u ed Any devi e can do a l g am nt f w rk by pe f rming f r a l ng ti at a low ate of p w r th t i l y d ing k l ly However if a la ge m unt of wo k m t be d ne rapidly a h gh p wer de i e red d ll gh p w m h n a e u ally larg r m ompl ated d m xpen i e tha equip m nt wh h ne d op ate nly t low p we A m t h h mu t l ft a cert in w ght w ll h t l l ger nd m e pow f l f t l ft the we ght p dly th lf t ra n it lowly An ele t i al t t m t be large s if it t e n t l tr al n gy into h t at h gh r t w tho t be ng d m ged

Electrical power The power P de el ped in a d re t nt el t ic ci cu t i $P = VI$ where V th appl d pot t al d ff ence a d I is the u nt. Th p w r g en in w tts if V i i It nd I in ampere In an alte at ng urr nt ircu t P VI s ϕ wh r V and I re the eff t e l es f th v lt ge and nt d ϕ th ph se gl betw n the curre t and the oltage *See* ALTERNATING CURRENT

Power in mechanics C de fo ce F whi h d k W a p rt cl *Let the m t n b* m t ted t o e d men n w th th di pl m nt in th d m g en by x Th n l y d fi ti n the p we t tim e will l g e by

$$P = dW/dt$$

In th eq t W ca b c d d as fun t n f e th r t x T e t ng W a a fun t n of x t es

$$P = \frac{dW}{dt} = \frac{dW}{d} \frac{dx}{dt}$$

N w dx/dt repre ent the vel city v of the parti cle an l dW/dx i equal t th e f rce F a cording t th e d fniti n f work Thus

$$P = Fv$$

This ften c nvenient expr i n f r power can l e g neraliz d to three d me i nal mot n In this ca e if ϕ i the angle betwe n the f r e F and the el ity v wl ich ha a magnitud F and v re p tively

$$P = F \cdot v = Fv \cos\phi$$

Th equation expre e quantitatively the ol erva t n th t if a machine is to l powerful it must run fast xert a large f r e r d both [P W S]

Power amplifier

The final tage in multistag amplifier circu it ch a audi mpl f ers nd rad o tran mitt r de igned to d l er app rec able p wer t th l ad

Power amplifier may l c ll d up n to upply p we ra g ng f m a f w watt in n audio ampl fi r t many th t nd f w tt in rad tra m tt r In ud ampl fier the l ad i u ually the dy am c imped nc p e ented to th mplif er by lo d peake a d the probl em i t m imiz the p wer d l r d to th lo d er a w de range of freq en ie The power mplifi r in radi tra s mitter ope ate o e a relati ely n rrow rang of frequen ie w th th l ad e nt ally a con t t im p dan

Th mod f peratio of p wer ampl f ers is d n ted l y Cla A AB B and C. Cl C opera ti n i lim ted t radi f equ nc es w th a tu ed lo d The the l s es may l e ised f audi and high f eq ncy p r t n F r d sc ion of th m d f p at on s AMPLIFIER

Class A power amplifiers Cla s A p rati n is u ed whe the am nt of p we transferred t the l ad rel t ely small ay le s than 10 watt The m nt f h rm i d to ti nt od c d into the l d ltag an l e kept m ll by us ng tubes w th ne rly l n ar cha ct ri ti and restr t ng the r nge l pe ation to a mall d pla m nt from the perating po t This cl of peration ha rel t ly l ttl use becau the pl t e re t eff i y (the effic ency of a p w r mpl fi r) l w The max m m p s ble eff i cy is 50% However f r the sual ope ating cond t ns and ia da d um t be th efficie cy s on th rd r f 10% If the p w r mpl fi r we e requi ed t del er 10 watt with 10% effi ien y the t be would ha e t b cap ble f d pati g an er ge p wer of 100 w tt Fu the mo e the p wer supply must b ca pable l supply g the p w r d ip ted heat by th tube pl th eful pow r del ered t the l ad Th p an u ne a y bu d n p n the p w pply Othe cla s f p ration ha a

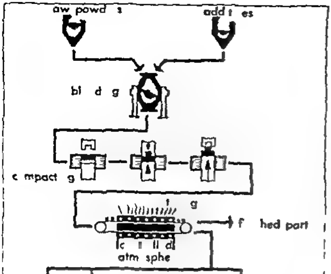


Fig 3 Flow ch rt for fabr cation of parts by powde metall rgy (M tal Powd r I d st es Fed rat n)

powder are produced by chemical precipitation reduction and electrol) i Stainle s steel powders can be produced effectively only l y chemical di integration of a pecially prepared heet metal but iron powder can be produced by at mization rea tion with olid or ga eous reducing agent electr l y i or decompo ition of iron carl nyl

Powder conditioning and processing technique The powdered raw material are cleaned dry stored and tested U ually they are mixed with lu *bricating agents to facilitate pres ing Very l rittle* metal or c mpound p wder require careful ad mixing of organic l inder to improve c herency during and after compaction Powder for alloy r compo ite tructure are prepared l y l lending de ired proportion of the ingredient This l lend ing operation i carried out under arious condi tions and usually with dry powder Often l lending is coml ined with l all milling I reca iti n mu t l e taken to prevent contamination deteriorati n or ignition of the powders during t rage handling or l lending

Mo t commonly the powder are pres ed t f rm coherent ma es and the resulting compact are sint red The pre ing op rati n i generally car ried out at ambient but sometimes elevated tem peratures The powd rs are confined in clo ed d es and heavy hydraulic or quick acting mechanical tableting pres es pro ide the compacting f rce

Rolling of powders into trips i another method of compaction In special ca es uch a the manufac ture of porous filter compre ion of the powder prior to intering i omitted entirely Mold that allow for hrinkage are u ed either bef re or dur ing sintering to impart the de ired hape to the powder ma When pre sing is done at ufficiently elevated temperature the intering operati n takes place under pre ure The application of heat during or after the compre sion of the powder pro duces a tructure with phy ical propertie compara ble to tho e of imilar material obtained by fu i n The sintered tructure however p o e es a fine poro ity which has an adver e effect mainly on duc tility The poro ity re ults from inc mplete den ifi cation during compre ion and from gas evolution during heating It cannot l e completely eliminated by the intering phenomena of diffu ion recry tal lization grain growth and hrinkage

Although the properties of the object after sin tering are frequently adequate for the fini hed product it is ometimes nece ary to improve them by further operation such a additi nal cold or hot compre ion metal working heat treatment or the impregnation of the pore with a l wer melt ing metal Certain other fini hing tep may al o l e required including machining plating buffing sanding grinding or barrel tumbling A numl er f applications require joining operation Brazing oldering or welding of the e parts nto other metal l a e is c mmon practi e in the hard metal and refra tory metal indu trie Fini hing and join ing operations mu t frequently l e adapted t the specific propertie f the e articles Thus care mu t l e taken in machining l e au e l the poro ity Plating meth d mu t l e adju ted to pre ent c rro i n cau ed l y the porosity and pecial fluxes or *inert or redu ing ga eou media mu t l e u ed to* pre ent ex e ive oxidati n during l razing and welding at high temperature

Critical evaluation A c mpari n of p wder metallurgy with m re orth dox m talli rgical meth od re eal the ad antage and limitations of the *method Thi may well erve a a gui le f r the* engi neer and manufacturer c nfr nted with the prol lem of electing the m t suital le pr ducti n method for a particular j b

Powder metallurgy d e not make up a prep n derant segment of the metallurgical indu try In spite of the accelerated gr wth f it different branche powder m tallurgy ha remaine l a lim ited and pecialized field The r a on f r th are both ec nomic and t chnical in natur I w lered starting material with the ex epti n f m t ir n powder are m re expen i e than other raw m ate rial T ol and dies mu t be d ral l nd u uall return their co t only when many th u and f the ame part are produced Special tool are required f r the f rming of ompl x sl apes be a e th p wder d e n t fl w r adily l t lat ral pr tr si n l wd r of high specific lum r quire l ng ompres i n str kes whi h in turn impos l w

Table 1 R p ese tative d m a d perfo m ce d ta on power pla ts

Type	U it s ra ge kw	F l	Pl t w ght lb/k	H at ft/k	H t at Bt /kw h
Central stat n					
hydr	10 000 100 000				
t m	10 000 00 000	CGN		0 0	8 00 15 000
d esel	1 000 000	DC			10 000 1 000
I dust l (by p od ct) team	1 000– 000	CCW		50	1 00 (000
D esel k om t	1 000 5 000	D	100 00	3	10 000 1 000
A to l l	→ 300	D	5 10	0 1	1 000– 0 000
O tl d	1 50	G		0 1 0 5	1 000 0 000
Truck	50–300	D	10 0		1 000 18 000
Mer h t h p d esel	5 000 10 000	D	300 00		10 000 1 000
N l esel st	000 100 000	DN	→ 0		1 000 18 000
Airpl ec procat en	1 000 3 000	G	1 3	0 0 0 10	1 000 1 000
Airpl t boj t	3 000	D	0 1		1 000 18 000

C coal D d sel fu l D di t ll t G ga G gasoli N n l W w te

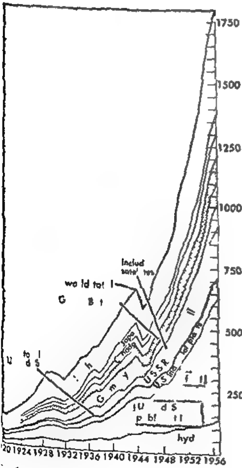
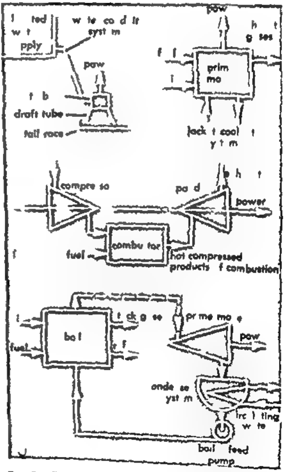


Fig 1 A l w ld p d t F l ct gy e t by ll g l d g i d try f t us (Ed El t I st t)



Fg 2 R d m ry fl w d g m f p w pl ts ( ) hyd (b) t l mb t ( ) g s t bin (d) d g t m

f and lar ad t o f egl g bl m n l g fi nc th g t f p w de- I t th t me d mag t de T ble 2 h w h e p f U ted St t p we pl t p ty abo t a th d f th w ld l t powe g e ted by U ted St te p bl c ut lity mpanies (F g 1) The d ta efl t the d m t p t l f l ge r ted power both f t t nary serv nd f th pr p l n f land wate and born h cle

higher plate-circuit efficiency and are therefore used for higher power applications.

Class AB power amplifier. An improvement in the plate-circuit efficiency can be had by using Class AB operation. However, while a Class A amplifier can be operated single-ended (one output tube), a Class AB amplifier must be operated push-pull. In Class AB operation the tube current does not flow for the complete cycle of the input voltage. In a single-ended circuit this would introduce excessive distortion. *See* PUSH-PULL AMPLIFIER.

Class B operation. This class is often used for the power amplifier in an audio amplifier. The amplifier in this class must be a push-pull circuit. Theoretically, with ideal tubes, the Class B amplifier can have a plate-circuit efficiency of 78.5%; practically, the efficiency is on the order of 50%, an appreciable improvement over that of Class A operation. Another advantage of Class B push-pull operation is that the average currents of the two tubes flow in opposite directions through the primary winding of the output transformer, resulting in no average magnetization of the core. This allows the use of smaller cores with savings in size and weight.

The load is transformer-coupled to the two tubes operating in push-pull. For maximum power transfer the dynamic load impedance presented to the amplifier should equal the conjugate of the output impedance of the amplifier when considered as an equivalent generator. In practice this is modified somewhat because the harmonic distortion is dependent upon the dynamic resistance. The choice of this load is therefore determined by the amount of harmonic distortion that can be tolerated.

The use of more sophisticated circuitry than that considered in an elementary presentation of a push-pull amplifier operating in Class B can produce nearly distortionless power amplification. This is of prime importance in the final amplifier stages of a high-fidelity audio amplifier.

Power amplifiers can operate in Class B_2 with an appreciable amount of grid current flowing for a small portion of the cycle of an input sinusoidal signal. This imposes additional requirements upon the driving circuit of the amplifier. If the equivalent circuit of the driver has too large an equivalent output impedance, the flow of grid current through this impedance will cause a distortion of the grid waveform. This problem is usually encountered in the design of driver circuits for Class B amplifiers operating in the radio-frequency region. Audio operation is usually restricted to Class B_1 operation because the usual form of phase-invertor circuitry has a large output impedance. In radio-frequency operation the transformer phase invertor can be used with tuned circuitry and air-core or powdered-iron slug coils because the operation is essentially at one frequency.

Class C operation. Because the plate current flows for less than one half cycle of the input sinusoidal signal, this class of operation is restricted to radio-frequency operation where a tuned load is employed. The load is usually the input impedance of an antenna or of an antenna matching network. The load voltage will be nearly sinusoidal even though the current in the tube flows in pulses because of the relatively sharp tuning of the load. This phenomenon allows the amplification of large amounts of power at plate-circuit efficiencies as high as 80%. This is extremely important for applications requiring delivery of large amounts of power to the load.

The driving source must usually be called upon to deliver power to the grid circuit of the power amplifier, in many cases as much as 10% of the power delivered to the load. This requirement is not excessive. A Class B power amplifier can be used in the grid-driving circuit to obtain a quite efficient combination of driver and final amplifier.

[H.F.K.]

Bibliography: J. D. Ryder, *Engineering Electronics*, 1957; S. Seely, *Electron Tube Circuits*, 2d ed., 1958.

Power factor

The ratio of watts average (or active) power to the apparent power of an alternating-current circuit (*see* ALTERNATING-CURRENT CIRCUIT THEORY). By definition and of general application

$$\text{Power factor (pf)} = \frac{\text{watts average power}}{\text{rms volts} \times \text{rms amperes}}$$

which is the ratio of instrument readings. A wattmeter indicates average power and electrodynamometer or iron-vane instruments show rms voltage and current. For the steady-state ac circuit under sinusoidal voltage and current, $pf = \cos\theta$, where θ is the phase angle between the voltage and current. This definition is restricted to sine waves of the same frequency. *See* WAVEFORM, NONSINUSOIDAL for the more general case. [B.L.R.]

Power plant

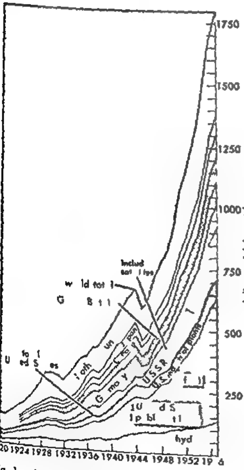
A means for converting stored energy into work. Stationary power plants such as electric generating stations are located near sources of stored energy, such as coal fields or river dams, or are located near the places where the work is to be performed, as in cities or industrial sites. Mobile power plants for transportation service are located in vehicles as the gasoline engine in automobiles and diesel locomotives for railroads. Power plants range in capacity from a fraction of a horsepower to 500,000 kw in a single unit (Table 1). Large power plants are assembled on location from components made by different manufacturers. Smaller units are manufactured ...

Most power plants convert part of the stored raw energy of fossil fuels into kinetic energy of a spinning shaft. Some power plants harness nuclear energy. For transportation, the plant may produce a propulsion jet instead of the rotary motion of a shaft. Other sources of energy, such as wind, tide

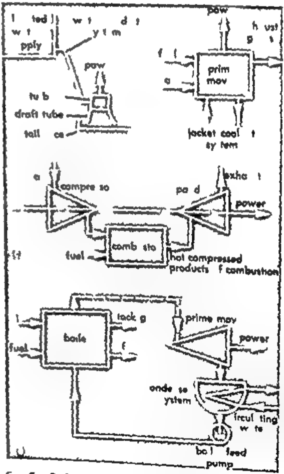
T ble 1 R prese tative design nd perform ce d t on power plants

Type	Unit m r g kw	Fu l	Il t w ight lb /kw	Il t f r ft /kw	H t rat Bt u/kw h r
Ce tral tat					
hydro	10 000 100 000				
team	10 000 500 000	CGN		0 0	00 1 000
d esel	1 000 000	DG			10 000 1 000
Ind t l (by produ t) t m	1 000 000	CCW		0 7	00 6 000
Deall nn t	1 000 000	D	100 00	3	10 000 15 000
A(ld	300	G	10	0 1	1 000– 0 000
0 tt u d	1 0	G		0 1 0	1 000– 0 000
T k	50 300	D	10 0		1 000 18 000
Mech t h p d esel	000 10 000	D	300 00		10 000 1 000
S l essel team	000–100 000	DN	0		1 000 10 000
Air fl rec p orat n nne	1 000 3 000	G	1 3	0 0 0 10	1 000 1 000
Airpl t boj t	3 000	D	0 1		1 000 18 000

C coal D desel f l D d still t G g s C gasol N n l W w te



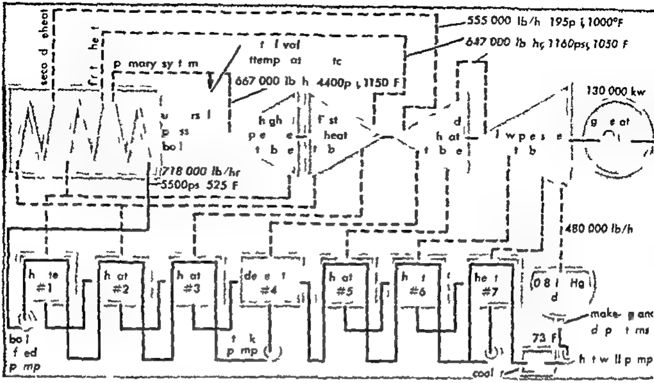
Fg 1 A l w ld p d f l ct e gy Ge o by ll g l d g d try f t o (Ed El ct l st tut)



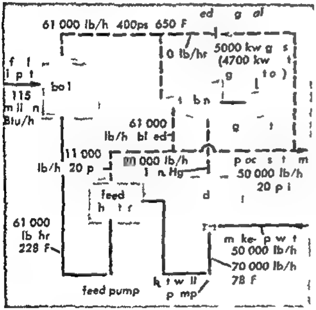
Fg 2 R d m t ry flow d g m f p w pla t ( ) hyd o (b) t l mbu t ( ) g t b (d) d g t om

a d sol r ad t n e f gl g ble m m l g fi a th t n f pow d pt th t m d u m g t d T bl h w th le I U t d St t P w pl t p ty Abo t a th rd f th w ld l t pow t g n

r ted by U ted State bl c tl ty comp m (F g 1) Th e d t fle t th d mina t p t n f f l g e ated p w r b th f t tona y s rvice and f th pr p l s of la d wate nd a r bo eh cles



Fg 3 S mpl fed heat balance fo a supe c t cal do bl reheat cycle Net ge e atro 119 000 kw pla t h at rate 8600 Bt kw h

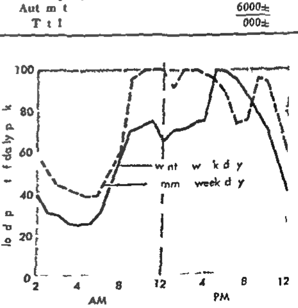


Fg 4 Heat bala ce fo a by p oduct ndu t al pow pl t del e ng both lectr e gy a d proc t am

Rudimentary flow or heat balance diagrams for important types of practical power plants are hown in Fig ▮ (*see* HEAT BALANCE) Many varia tions are incorporated *for the ontrol of efficiency* weight space flexibility reversibility reliability life inve tment and operating costs Figure 3 hows a heat balance diagram for a modern team electric central tat on *Figure 4 is a similar dia* gram for a by product type indu trial plant which

Table 2 Approximate installed capacity of Un ted States power plants (1957)

Pl t type	C pa ty mill ns f kw
Elect i cent l tat ns	130
Indu t l	30
Agr lt l	50
R lroad	[illegible]
M e c l n	0
A ft l	0
M l t ry est bl hment	1000±
Aut m t	6000±
T t l	000±



Fg 5 S l ct d da ly load urv for a b n ut l ty pl t

T bl 3 R g of cap city f ctors
for selected power pl ts

Public tility y t m ge l	50– 0
Chem cal or m t ll gical pl t th ee-sh ft pe on	80–90
Seam g h ps, l g y ges	0–80
Seago g h ps, hort y ges	30–40
Airpl es, comm ci l	0–30
Pr t passenger m	1 3
Main-li locom t m	30–40
Interu ba b ses d tru ks	5 10

has th d ble purp e of ge erat g ele tric power a d m ltaneously del ering h ating team b tracti xh u t from the pr me m er

Plant load There is no p ct al way f st ng the mecha l elect ic l tp t of p wer plant n th m gnit de co tered i p we plant ppl cati Th utp t m t be g erated t the instant of ts u Thi r ult i w de iati ns i the l ad imp sed up n a pla t The cap ty m ed i kw hp mu t be a lable when the lo d imp ed M ch f th capac ty may be dle d g xt ded p od wh th r s no dem nd f utp t. He m h f the potent al tput a ured s kw h o hp hr t be gene t d bec se th r i n dema d f o tput Th greatly c pl t the de ign d o f se the eco om c l po er pl nts Kil w tts t be tr d d fo kil tt h s nd vi er

Th u of a er g l d t r t d apa ity or pe k l d se p ss d

$$\text{Cap ty f t} = \frac{\text{r l ad f th pe d}}{\text{ted o st lled capac ty}}$$

and

$$\text{Lo d fa t} = \frac{\text{l d f r th p d}}{\text{pe k l d n th p od}}$$

Som xp n d c p ty fact a e gi n Table 3.

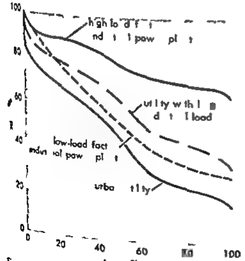


Fig 6. An al lo d-d t rv f l t d t tionary pow pla t

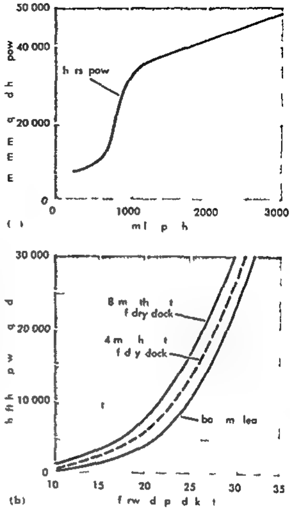


Fig 7 ( ) M m m p w d t d a 50 f w ll-d g d pl t ght l v l flight at 30 000 ft lt t d (b) P w q d t d hp h w g ff t f f l g

Variation n l ds can be on e tly h wn n gr phi l b a F gs 5 d 6 for p bli utili ti d F g 7 f r a r a d m p p l H r d fi t f l d f cto s n t p ble w th h l l k t to aut mobil be au f t th h r te nd o d t o f th r g f l p p ls ppl cat ns p w utp t (kw hp) may be f sec d ry s gn fi nd p f rm c may be ba d o t a t eff t d wb p ll th t cl mb d ac le t o

Plant efficiency Th effi ncy f e gy n e o i t f i m t pow pl t in t ll t ns The theo et p w f a hyd o plart n kw is $QH/11.8$ wh e Q the fl w in ub f t pe d nd H s th h ad at the u n f t Lo e li dw k pe t ks tu b e d ft t b t l r b ar g e ato d u l es w ll e d e th l ble tp t 15–20% bel w th the ret in mod rn t ll t n The el t of p rt la typ wat r wh l d p d pe n ce w th wh l t th pl n ed p ed d n th l w t

Table 4 Cost of selected stationary electric power plants (investor-owned and business managed)

	Steam central station		Hydro		Steam industrial	
	Large	Small	Large	Small	Large	Small
Plant capacity kw	500 000	50 000	[illegible]00 000	20 000	10 000	1 000
Investment $ per kw	150	[illegible]0	200	300	1 5	22[illegible]
Fuel co t cents per mill on Btu	[illegible]0	30			30	40
Cost of power mills per kw hr						
Total cost	4 7	13 0	3 5	6 5	5 2	9 0
Carrying cost on investment	[illegible]5	5 7	3 0	5 [illegible]	3 3	5 0
Production cost total	[illegible]	7 3	0 5	0 8	1 9	4 0
Fuel	1 9	4 3			1 3	[illegible]0
Labo maintenance suppl es supervision	0 3	3 0	0 5	0 8	0 6	[illegible]0

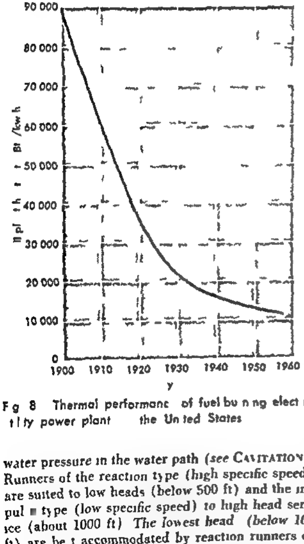


Fig 8 Thermal performanc of fuel bu n ng elect ic t l ty power plant the Un ted States

water pressure in the water path (*see* CAVITATION) Runners of the reaction type (high specific speed) are suited to low heads (below 500 ft) and the im pul e type (low specific speed) to high head serv ice (about 1000 ft) The lowest head (below 100 ft) are be t accommodated by reaction runners of the propeller or the adjustable blade types Mixed pres ure runners are favored for the intermediate heads (50–500 ft) Draft tubes which permit the unit to be placed safely above flood water and with out sacrifice of site head are essential parts of re action unit installations

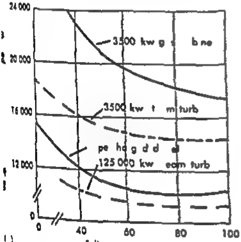
With thermal power plants there are the bas c limitations of thermodynamics which fix the effi ciency of conversion for heat into work The cyclic tandards of Carnot Rankine Otto Diesel and Brayton are the u ual criteria on which heat power operations are variously judged Performance of an assembled power plant from fuel to net salable or usable output may be expre sed as thermal effi ciency (%) fuel consumption (lb pt or gal per hp hr or per kw hr) or heat rate (Btu supplied in fuel per hp hr or per kw hr) American practice u es the high or gross calorific value of the fuel for measuring heat rate or thermal efficiency and dif fers in this re pect from European practice which prefers the low or net calorific alue Tables 1 and 3 give performances for everal selected opera tions Figure 8 reflects the improvement in fuel utilization of the United States electric power in du try since 1900 Figure 9 shows ariation in heat rate with load for everal types of stationary plants and marine power plants

In crutinizing data on thermal performance it should be recalled that the mechanical equivalent of heat (100% thermal efficiency) is 2545 Btu/hp hr and 3413 Btu/kw hr Modern team plants in large size (75 000–500 000 kw units) and internal combustion plants in modest izes (1000–5000 kw) have little difficulty in delivering a kw hr for less than 10 000 Btu in fuel (34% thermal efficiency) Lowest fuel consumptions per unit output (8500–9000 Btu/kw hr) are obtained in conden ing steam plants with the be t vacua regenerati e-reheat cycle using eight stages of extraction feed heating two stages of re uperheat, primary pres ures of 5000 psi (supercritical) and temperatures of 1150 F *An industrial plant in* which ele tric power is generated as a by product of the proce s team load can have a thermal efficiency of 5000 But/kw hr

The atomic power plant substitutes the heat of fis ion f r the heat of combustion and the con e quent plant differs only in the method of preparing the thermodynamic fl id It is otherwi e milar to the usual thermal power plant Low reactor tem peratures lead to the overwhelming preference for

steam turb ther th gas t rb ne cycle When f d tempe at res ca be had ab e 1200 F the p po er c le ll rece e m re fa rable n d u n. Otherwi e the atom c powe plant s- ent lly a l w pe u e low tempe tu e st m perati n (less th n 1000 psi nd 600 F)

Power economy Co ts are a ig fic t a d often co t ll g f ctor i ny c mme ial p wer pl t applicati n. A e g st ha e little ig fica ce be se f the ma v ariables pecially l d f t r Som pl ts r hort l ed a d others l g lived. For e ample in m t aut mob les which have short li ed pow r plant 100 000 m les a d 3000 h o titute perat g life die el l om tives, h h will r n 20 000 m l a m nth with com p t overh uls e ery few ye s a d la ge eag hps, h h reg te 1 000 000 miles f tra el and till g ev ll t erv e afte years of opera tion, h e l g l ed pl ts lectric c tral ta tion f th hydr t pe rema in serv 50 y ars and st am pla ts ru r d the cl ck a d pward 18000 h ur a ye w th c mplete li b lity even



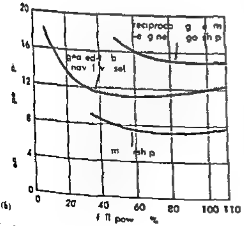


Fig. 9 Comp so f h at rate f sel ct d typ f (a) h ry pow pl ts d (b) m p o- p lsion pla ts.

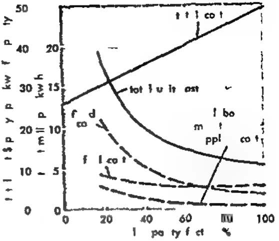


Fig 10 R p e t t t of p w f om a l g t m-el ct c ge t g t t o

when 25 ye old Such fig res greatly influ ence c ts Fu th rm ts a open to wide differ enc of terp tatio

Co t re flect d n th curve of Fig 10 f r moder st am electric est r ow ed ntral sta ti in the ea t rn U ited Stat Fixed c t a e based on $150 per kw i estme t with 12% ann al arryi g ha g If uch plant were g ernme t fin ced the ann al charge an i e tment f $150 p r kw might be red ced t 6% F el c t is t 30 ts per mill n Btu T tal c t of p wer c n b on en e tly pressed as

$ per kw per yr

$$= K_1 + K_2 + 8760\ K_3 \times \text{capac ty facto}$$

whe e K_1 = apacity charge $ per yr
K_2 = pe k prep ed ch g $ p yr
K_3 = energy cost mills p kw hr

C sts of represent ti e p wer pla are summa ized in Table 4 [T B]

Bibl g aphy E. Ayres and C. A. Sc l tt *En e gy S ces—th W lth of th Wo ld* 1952 Bab k and Wilcox Compa y *St am Its Gen* d U H K B rrows *W te P u E g g* 3d d 1943 T Baume ster (d) *M ks M h al Engi Ha db k* 6th ed 1958 C. F B ll *N l E gi ng* 1957 G A Sk otzk d W A V pat *Appl d E gy Co st* 1945

Power supply electronic

A fel t gy employed to f h th t bes d emi du t r dev l an l ct on c u t with th p per el ctr c lt ge nd t f th r p rt n The m r c mmo ur s f gy e h m l batt e a d lt n t t m o l ne B tt es f l a p rt bl e b t p n i e a d ha mall a p it Alt n t g t ma t p t bl b t r l t ly xpe a d h a l g p ty

One common method of classifying power supplies is by their use in electronic circuits. Most vacuum and gas tubes require a source of energy to energize their filaments or heaters; this type is known as a *filament or heater power supply* or simply as an A supply. Tubes require plate or anode voltages, and transistors need voltages for their collectors and other elements. These voltages are supplied by a plate or anode power supply, sometimes called a B supply. Similarly, the tubes may also require a control grid power supply, often called a C supply, and additional power supplies for the screen grid and suppressor grid.

If the source is one of alternating voltage, a transformer is usually used to raise or lower the voltage to the required level. The alternating current (ac) usually must be changed to a direct current (dc); this is accomplished by a rectifier. A rectifier allows current to flow mostly in one direction, and a pulsating current results. This pulsating direct current is not suitable for most purposes and must be smoothed by a power supply filter or voltage regulator.

A power supply filter stores energy when the current is high and gives it up when the current is lower. The net result is to smooth out the variation in the current. The voltage regulator performs a similar function, but its operation is quite different. The gas tube type of voltage regulator has a characteristic constant voltage over a large range of current values. Vacuum tube regulators usually operate as variable resistances; the resistance decreases when the load is heavy and increases when the load is lighter. Voltage regulators deliver an almost constant output voltage in spite of variations in the load or in the input ac supply voltage. *See* VOLTAGE REGULATOR.

Filament or heater power supply The filament or heater power supply is used to heat the filaments of vacuum or gas tubes so that electrons may be emitted from the filaments. If an indirectly heated cathode is used, a heater element inside the cathode must heat the cathode to a temperature at which electrons will be emitted.

Most of the present day tubes heated by alternating current use 6.3- or 12.6-volt heaters. A stepdown transformer is employed to change the 115 volts of the ac lines to these voltages. As an example, the heaters of four tubes may be connected in parallel across the secondary of a heater transformer whose primary is connected to the 115-volt ac lines. The center tap or one side of the secondary is often grounded. The tubes might take 0.5, 0.5, 1.0, and 2.0 amperes, respectively, for a total of 4.0 amperes. The heater transformer must have a rated capacity of at least 4.0 amperes to supply these tubes. The voltage that the insulation must withstand is also often stipulated. Some tubes require other heater voltages, such as 2.5, 5, and 25 volts. Therefore, heater transformers with more than one secondary are useful.

Heater transformers are both heavy and expensive. To eliminate transformers, heaters may be connected in series across the ac line. Here each heater must take the same current, and the sum of the heater voltage ratings must be nearly equal to the ac line voltage. Other tubes use heaters made for direct connection across the ac lines.

For portable operation, batteries are usually used to heat the filaments. The tubes usually require 1–3 volts, so that one or two cells of a dry battery or one cell of a wet battery will supply sufficient voltage. Tubes having 6.3- or 12.6-volt heaters may be operated from a wet storage battery, such as an automobile battery, but the weight of the battery decreases its portability. The filaments of the tubes are connected in parallel, and one side of the battery is connected to the plate supply so a complete circuit exists for the electrons flowing in the tube.

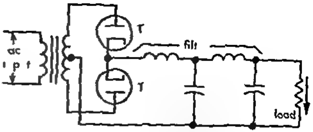


Fig. 1. Typical plate power supply.

Plate power supply The plate power supply usually supplies direct current of about 50 to 300 or 400 volts, depending on the tube and the application. Figure 1 shows the schematic diagram of a typical supply. The ac line energizes the primary of the transformer; the secondary is connected to the anodes of the rectifier tubes T and T. The heater connections of the rectifier tubes are omitted for clarity. The common cathode connection is connected to the double-section *L* filter. This is the positive side of the filter. The negative side, usually grounded, is connected to the center tap of the transformer secondary. The load resistance is shown at the other end of the filter. A bleeder resistor is sometimes connected across the load to prevent the output voltage from increasing to dangerous values when the load is light.

The power or plate transformer should be selected to have a sufficiently high secondary voltage to supply the desired output voltage. Allowance must be made for the voltage drop or rise caused by the type of rectifier circuit employed and for the voltage drop in the rectifier tube and the filter elements caused by the combined load and bleeder currents. Also, the transformer secondary current rating must be sufficient to supply the combined currents. The rectifier tube or tubes must have voltage ratings sufficiently large for the transformer secondary voltage and current rating sufficiently large for the combined load and bleeder current and for the peak current encountered in the particular rectifier circuit used. The filter capacitor should have sufficient capacitance for smoothing the ripple of the output voltage and sufficient voltage rating. The filter inductor should have sufficient inductance for smoothing, low resistance, to the current carried, and high insulation voltage.

the line voltage fluctuates, the output dc voltage will fluctuate. One method of reducing this effect at n t regulat the ltag of the clnesh t t ac olt ge reg lat r

Control grid power supply The control grid power supply is used to supply voltage of 1–100 lt grd b a to the contr l g d of acuum tube. This u u lly do e by th f bia ing re t r m se th th B upply and the v uum tube b t s pa ate C upply im l r t th al o men n ed B supply s ometimes mpl yed U ually th lta e a d c rre t eq ments ar m ch m ll r for th C pply than f the B upply S l r uppl ed cc nally t f m h th ltages requ red for the reen gr d and up p r g d of a u m tubes

High voltage power supply High ltage p w r supplies a e employed to upply d oltages of 1 00 k l lt m re s ally at u r t of a few mamp r le Volt d ubling and voltage m luply g e t f r cu t are ef l in t h pplicat ns h ch t l d th athod r y tube po e s pple f t le on a d da (s VOLT AGE MULTIPLIER CIRCUIT) An ther meth d f b t ng hi h olt g s t e a fly b k p w r p pl e t w th a h lf wa e tifi and filter r th a lt ge mult pl er t u t For hea y ur nt h gh lt g pples t uch th t of F 1 alm t alw ys d All mp n nts f the t m t tl n b le t d f tl r qu em nts of th h gh lt g and h gh u t

Battery power supplies Th a ef l f r portable ppli ation wh l w lt ge and nts a l Th p t c la ly true f t a t t D y b ttery n ts ar u ed A B a d C upply qui eme t W t torag b t may b u d di e tly f the heate s of t h a d ay al pply B a d C p wer equir m nt by th f br t r dynam t r p we r ppl

Power supply filters Power upply filt e ally f th l w p RC a t ly w th th ut f q cy f th filte m d s m h b l w the fu dam tal f eq cy f th r pple v lt ge a m m lly f ble O a ally l w pa RC filt ll b u d f th l d t nt r qu ment a e m ll (e e lly l w t off f eq en e q l g d ta e l pa tan Th a tw bd f th filter Th fir t alled n d t p t filt h a e es n t t mm d t ly ft the tifi Th c nd th r t p t filt wh h h a h t b t mmed t ly ft th r t f r O r m t m b d h n i F g 2 F g h w gl h nt ap t th moothi g l m t F g 2b h w a two- t n d t e p t filt F g 2 g n a t o t f t p t filt r Th d t p t filt r h th d d t g f g ng l w tp t ltag b t tl l a t g f b ett lt g r g l t th t p t p f lt Th p t y p t filt h tl imp t t d d t g f p o l g m h l gl p k t t n th t f r

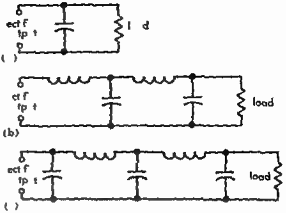


Fig. 2 Smoothing filters. ( ) Sh t c p t f (b) I d t p t filt r ( ) Capa t p t filte

The i d ct met mes c lled choke coil al mo t alw y have iron c e and the re i tance of the w d ng re k pt low fo high effici ncy and go d ltag regulat on I n c ed inductors an be m d t h e an i du tan th t in re s c n iderably a the l d ur nt appr a he ze o Th e du t rs alled wi gi g hoke coil l lp p event th la g i e n v ltage at l w load cur rents in ap it e i p it filte Capa ito s f oltages bel w 500 v lt are lm t always elec tr lyt pa ito b t l o e that ltag they pap pl ti ns lat n S e CAPACITOR I DUCTOR f th typ and g n al t atment of l ctr c t CIRCUIT ELECTRO IC.

[D L W]

Bibliography J M Car ll *Tr ns st Ci cu t a d Appli at* 1957 H E Cl fford nd A H W g (ed) *Ele t C u ts and Tube* 1947 J Millman and S S ely *El ct o c* 2d ed 1951 H J Rei h *Tl y a d Appl at ns of El ct on T b s* 2d d 1944 S Seely *Ele tr ic E g* 1956

Power factor meter

An instrument u d t i dicate whether l ad cur r t and v lt g a in t m pha e with one a othe

In n lte t ng urrent i uit the curr t I m y l d r lag the lta e E by me ngle ϕ and th ve age powe P w ld l th av rag f

$$(E_m \; s \omega t)[I_m \; (\omega t \pm \phi)]$$
$$P = EI \; o \; \phi$$

Th f t r c s $\phi = P/EI$ is lled th p wer f t r f th l d S ALTERNA I G CURRENT CIRCUIT THEORY

Th f rmula P EI ϕ how that if tw u tome eq al c nt the en rgy lo th l n s th am f th tw If ne f them ha a l we p w r f ct he le t b d nly gy d l e d o ld n ol e n n qu l ch rg f r e

Single phase power factor meter Thi i stru ment nt a fi d l th t arri th load cu nt and o d ils th t a e n e ted t th

load voltage There is no spring to restrain the moving system which takes a position to indicate the angle between the current and voltage The scale can be marked in degrees or in power factor For a complete discu sion of this instrument *see* PHASE METER

The angle between the currents in the crossed coils is a function of frequency and consequently each power factor meter is designed for a single frequency and will be in error at all other fre quencie For low harmonic content the indication of the power factor meter is usually accepted for contract purposes

Polyphase power factor meters *These meters* are usually designed differently from single phase meters For balanced polyphase loads their appli cation is straightforward For a quarter pha e load two voltages 90 out of phase are present and each can supply one of the cros ed coil of the power factor meter If the voltages are unequal or their relative phase angle is different from 90 the indication will no longer have meaning

Three pha e power factor meters are built to con nect the fixed coil in one line and the cros ed coils between the other two lines The meter is con structed with a 60 angle between the crossed coils An unbalan e in either voltage or angle will cau e erroneous readings

In the case of balanced four pha e and balanced six pha e loads single phase power factor meters can be used directly without any correction

In the ca e of unbalanced polypha e circuits with harmonics various portions of the load may ha e different power factors and for the combined load there i no common pha e angle con equently the statement that the power factor is equal to cos ϕ becomes meaningless *See* WAVEFORM NONSINUS OIDAL [H SO]

Bibliog aphy F A Laws *Electrical Measure ments* 2d ed 1938 M B Stout *Basic Electrical Measurements* 1950

Poynting s vector

A vector the outward normal component of which when integrated over a closed surface in an electro magnetic field repre ents the out ard flow of energy through that surf ce It is given by the equat on

$$\Pi = \mathbf{E} \times \mathbf{H} = \mu^{-1}\mathbf{E} \times \mathbf{B} \qquad (1)$$

where E is the electric field stren th H the mag netic field strength B the magnetic flux density and μ the permeability This can be shown with the aid of Maxwell s equations

$$\mathbf{H} \quad (\nabla \times \mathbf{E}) - \mathbf{E} \quad (\nabla \times \mathbf{H}) = \nabla \quad (\mathbf{F} \times \mathbf{H})$$
$$= -\imath \quad \mathbf{E} - \mathbf{F} \quad \frac{\partial \mathbf{D}}{\partial t} - \mathbf{H} \quad \frac{\partial \mathbf{B}}{\partial t} \qquad (2)$$

where D is the electric di placement and i the cur rent density Integration o er any volume v and u e of the di ergence theorem to replace one volume integral by a surface integral give

$$-\int(\mathbf{E} \times \mathbf{H}) \quad \mathbf{n}\, dS$$
$$= \int \left[\frac{\partial}{\partial t}(\tfrac{1}{2}\mathbf{B} \quad \mathbf{H}) + \frac{\partial}{\partial t}(\tfrac{1}{2}\mathbf{D} \quad \mathbf{E}) + \mathbf{E} \quad \imath\right] dv \qquad (3)$$

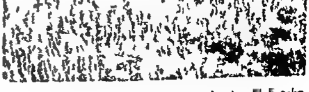
where n is a unit vector normal to dS In the volume integral ½B H is the magnetostatic energy den sity and ½D E is the electro tatic energy density o the integral of the first two term represents the rate of increase of energy tored in the magnetic and electric fields in v The product of E i is the rate of energy dissipation per unit volume as heat or if there is a motion of free charges so that i is re placed by ρv ρ being the charge density it is the energy per unit volume u ed in accelerating the e charges The net energy change must be upplied through the surface which explains the interpreta tion of Poynting s vector

It should be noted that this proof permits an in terpretation of Poynting s vector only when it is integrated over a clo ed surface In quantum the ory where the photons are localized it could be interpreted as repre enting the statistical di tribu *tion of photons over the urface Perhaps this ju ti* fie the common practice of u ing Poyntin s vector to calculate the energy flow through a portion of a surface

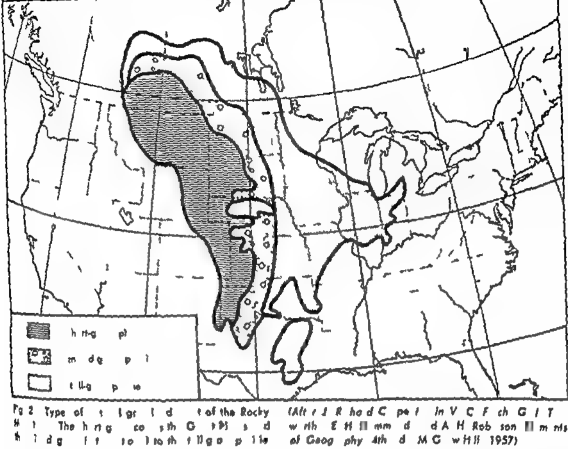
When an electromagnetic wave is incident on a conducting or ab orbing surface theory predicts that it should exert a force on the surface in the direction of Poynting s vector *See* RADIATION PRES SURE *see also* ELECTROMAGNETIC RADIATION MAX WELL S EQUATIONS WAVE EQUATION [W R S I]

Prairie

A land of tall gras es occurring in the humid or subhumid parts of the mid latitudes between the forests and the emiarid short grass steppes The North American prairies are better known than those of other continent The tall grass prairies occur on the more moi t ide tow ard the fore t margins They consist of tall gras e 5–8 ft in height together with a variety of flowering plants



Fg 1 M ed-g ss p a e nea Agat N B aska Th hort-g ass part a e a f ot or le s i he ght (F m J E W a a d F E Cl me t Pla t E l gy 2d ed McGraw-H ll 1938)

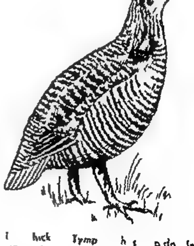


Fg 2 Type of t l gr l d t of the Rocky M t The h rt g co s th G t Pl s d th l d g l t to l to th t ll g o p l ie (Alt r J R ho d C pe l in V C F ch G l T w rth E H ll mm d d A H Rob son ll m nts of Geog phy 4th d M G w H ll 1957)

t es are ab nt n re th gl d T war l tl dry s de the mix d g pra r are apparently a tr n t on int the h rt g t ppe Th y l ar some g a ses 2–4 ft t ll a d oth whi h re l th n l ft h gh Pr g w in l matic t tl n wh e the e t en ugh fall f r p They oc cur on el t ly l el land d h lev l pel d p dark f tile s il Fo the a n m t p a g tat n ha b n di pla d l y agr l t r nd l ttle rig l p a t l d rem n in th w rld The pr r f N rth Am t a f m rly bo e a te ve n m l p pulati n f l l l anl small m mm ls t g ther with g g a m l th fly the b n Th e m l d app r l w th th n r n f th prai i int r pl l S Sterpr [r m n]

Prairie chicken

E th f tw Am a gam b d f th g *Tymp h* f m ly T t nd th gr f m lly Th g ate p h k n *T p lo* f r m ly w imp rt nt g m l rd f th Cr at Pl l t t h d ppear d t ly th gh t m ch of t g l d rac f the re m i der W th h ges grs lt th pr p l pop l t n f th b rd ha hift d int th Can d pr n l recent y The e t n r p t t f th pec th b ath h n



Th p l hick *Tymp h t p do* le gth t 18 4 t (F m E L P ime Fieldb k of N t l H t y M G w H ll 1949)

f rm rly f nd on the Atl nt c c a tal pla n n w xt nct Th l r pra i chi k n *T palli d tus* i p ler th n *T p d* and i re d in the so thw tern plai

load voltage. There is no spring to restrain the moving system, which takes a position to indicate the angle between the current and voltage. The scale can be marked in degrees or in power factor. For a complete discussion of this instrument *see* PHASE METER.

The angle between the currents in the crossed coils is a function of frequency, and consequently each power factor meter is designed for a single frequency and will be in error at all other frequencies. For low harmonic content the indication of the power factor meter is usually accepted for contract purposes.

Polyphase power factor meters. These meters are usually designed differently from single phase meters. For balanced polyphase loads their application is straightforward. For a quarter phase load two voltages 90° out of phase are present and each can supply one of the crossed coils of the power factor meter. If the voltages are unequal or their relative phase angle is different from 90°, the indication will no longer have meaning.

Three phase power factor meters are built to connect the fixed coil in one line and the crossed coils between the other two lines. The meter is constructed with a 60° angle between the crossed coils. An unbalance in either voltage or angle will cause erroneous readings.

In the case of balanced four phase and balanced six phase loads, single phase power factor meters can be used directly without any correction.

In the case of unbalanced polyphase circuits with harmonics, various portions of the load may have different power factors and for the combined load there is no common phase angle; consequently the statement that the power factor is equal to cos ϕ becomes meaningless. *See* WAVEFORM, NONSINUSOIDAL. [H.SO.]

Bibliography: F. A. Laws, *Electrical Measurements*, 2d ed., 1938; M. B. Stout, *Basic Electrical Measurements*, 1950.

Poynting's vector

A vector, the outward normal component of which, when integrated over a closed surface in an electromagnetic field, represents the outward flow of energy through that surface. It is given by the equation

$$\Pi = E \times H = \mu^{-1} E \times B \qquad (1)$$

where E is the electric field strength, H the magnetic field strength, B the magnetic flux density, and μ the permeability. This can be shown with the aid of Maxwell's equations.

$$H \cdot (\nabla \times E) - E \cdot (\nabla \times H) = \nabla \cdot (E \times H)$$
$$= -i \cdot E - E \cdot \frac{\partial D}{\partial t} - H \cdot \frac{\partial B}{\partial t} \qquad (2)$$

where D is the electric displacement and i the current density. Integration over any volume v and use of the divergence theorem to replace one volume integral by a surface integral give

$$-\int (E \times H) \cdot n\, dS$$
$$= \int \left[\frac{\partial}{\partial t}(\tfrac{1}{2}B \cdot H) + \frac{\partial}{\partial t}(\tfrac{1}{2}D \cdot E) + E \cdot i\right] dv \qquad (3)$$

where n is a unit vector normal to dS. In the volume integral, $\frac{1}{2}B \cdot H$ is the magnetostatic energy density and $\frac{1}{2}D \cdot E$ is the electrostatic energy density, so the integral of the first two terms represents the rate of increase of energy stored in the magnetic and electric fields in v. The product of E · i is the rate of energy dissipation per unit volume as heat, or, if there is a motion of free charges so that i is replaced by ρv, ρ being the charge density, it is the energy per unit volume used in accelerating the charges. The net energy change must be supplied through the surface, which explains the interpretation of Poynting's vector.

It should be noted that this proof permits an interpretation of Poynting's vector only when it is integrated over a closed surface. In quantum theory, where the photons are localized, it could be interpreted as representing the statistical distribution of photons over the surface. Perhaps this justifies the common practice of using Poynting's vector to calculate the energy flow through a portion of a surface.

When an electromagnetic wave is incident on a conducting or absorbing surface, theory predicts that it should exert a force on the surface in the direction of Poynting's vector. *See* RADIATION PRESSURE; *see also* ELECTROMAGNETIC RADIATION; MAXWELL'S EQUATIONS; WAVE EQUATION. [W.R.SM.]

Prairie

A land of tall grasses occurring in the humid or subhumid parts of the mid-latitudes between the *forests and the semiarid short-grass steppes*. The North American prairies are better known than those of other continents. The tall-grass prairies occur on the more moist side toward the forest margins. They consist of tall grasses, 5–8 ft in height, together with a variety of flowering plants.

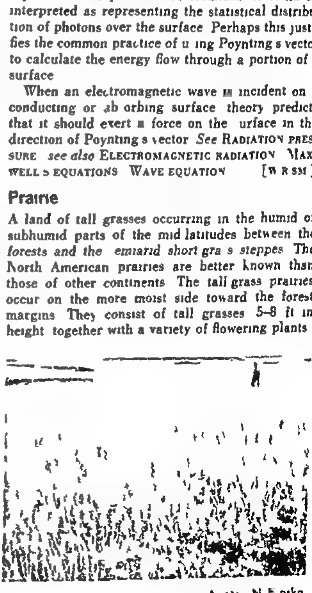


Fig. 1. Mid-grass prairie near Agate, Nebraska. The short-grass ... less in height. (From J. E. Weaver and F. E. Clements, Plant Ecology, 2d ed., McGraw-Hill, 1938)

lent f rm. The bl k o de dis ol e m acid w th the libe at o f oxygen to g g een olutions or green lts F r p p rt es of the m tal *see* RARE E RTH ELEME T

The alt h e fo nd ppl ti n n the ce amic d try for col r ng gl s nd f r gla e

[F H SP]

Preamplifier

A ltag mpl fi r su t bl f r oper tion with lo les l input g al It i t nded to be c n erted t an the ampl fie with hi her input level. P mplifi ar nece sary wh n a aud o ampl fie is t be ed w th l w o tp it t a sdu s m h magn t ph n g ph p k p The p eam plfi m y al o rp at f equency corr cting et ks t mpe at f the f q n y ha ac terist f g tra d c nd make the fr quency esp of th pre mplifie ampl fi r om b u u if m S VOLTAGE AMPLIFIER

The de ig f p eampl fie s r tic l b th inp t gnal level l w nd the mpl fic t n is h gh. Th h m i t d ed by tube a d th n lt ges f m res t s d a u m t be m t b losely c t ll d F rth m re the p amplifie st b h lded f m t n l magn t field a h ld du lt g i th c cut An d t n l ce of de able ltag i m o- h F a d i n f the nd s abl t *se* AMPLIFI

[H F K]

Precambrian

Th m f r k ld r th n th C mbr an r le t p od th e th h st ry wh h b n l t f l i d t th ex ten e f l fe B c e

PRE CAMBRIAN		PALEOZOIC							MESOZOIC			CENOZOIC	
A H OZO (EA R CAM AN)	PROTEROZO C (LATE PRECAMBR AN)	CAMBRIAN	ORDOVICIAN	SILURIAN	DEVONIAN	CARBONIFEROUS		PERMIAN	TRIASSIC	JURASSIC	CRETACEOUS	TERTIARY	QUATERNARY
						MI l lpp	P yl						

f the lde age P e mbr k l at the b se f th cce f f rm t d n th h l h e d g m t f mat n th n th ock f l t g l pl Camb n t t p t t lly d w w d t th P e mb b t m mm ly th y p t d by te l f d g wh h th r k w w d w t p od f m ty S C MB IA L o n

F l h lpl l d t rm g th ag f y g ock lm t t ely b th P ec mb Th l th q e f k w th th P mb y t m m t be d t

F g 1 St t d d f t d pebbl f m P mb gl m t f gl l g th K k k H ll W t O b C d (M E W l I S y C d)

mi d by det il d t ct ral examinati n by the lat n hip t u c nf rmit e r g eo s ntru n o f m th r to of s tope in ad ct e m e al d t mi d by ge phys al meth d R d a u mn al h w mmo ly oc u in f lded mo t b ilt k that th s m n ly th t f th m u ta b ld g th n th ge f th e cl k wh h may be m ll on of ye lde Th m x m mag f Pre ambri n m e l f r d t mi d by ge phy c l meth ds ab t 3×10 y s S RADIOACTIVE MINERALS ROCK (AG DETER INATION)

Occurrence P ambr n r ks w d ly d s- t b t d They o all the t ts d un d l e bo t e fifth f th th fa e St u t rally they m nly n tw typ f ar as (1) n the t f p tly d ded m ta n (2) in xt as f al t ely l w elev t n lled h ld Wh m ta n h s ar formed by f ld d pl ft Pre mb an rock com m ly t ded by ma f g te elat d g k thr st pw d by th m ta n b g m m t H w e n f the m nt t es th Pr c mb an k nd th t d igneo s i tr s be me ed Th h eld f the e rth als a un d l m ly by m t b lt rocks b t h b d ded th t they ar m t ns st t lly d t by l t n

Th lde t P ecamb i fi ial r ck e ch fly l a f gme t l m te al bl w e pl ely fr m lc d bedded d m nt The d m ts tably g ls (gl me t) and t r t t l med le t q rtz te m dl ke d pos t (g yw k) l c mm ly l mest These k e im l to th e b g f rmed on th th fa today Fu th mo in m r

Prairie chickens are noted for their elaborate mating rituals involving participation in dancing and drumming (booming) by aggregations of males on elected booming ground See GALLIFORMES GROUSE [J D B]

Prairie dog

Any of three species compri ing the genus *Cynomys* Prairie dogs are rather large stout bodied terrestrial squirrels with small ears and short flat tails They live in large colonies called towns digging burrows for their homes each surrounded by a mound of earth Of the two species in the United

The p ■ ie dog *Cynomys l dovic anus* length to 14¼ n (F om P M D con ed Cass ll s Nat ral H st ry Cass ll)

States one hibernate and the other is active throughout the winter They feed mainly upon plant material but will al o eat in ects They are much less common than originally many of their great towns now being completely wiped out In 1900 one colony in Texas was estimated to be 100–150 miles wide and 250 miles long Burrowing owl rattlesnakes and the rare black footed ferret prey upon young prairie dogs and are unwelcome predators in their burrows See RODENTIA [J D B]

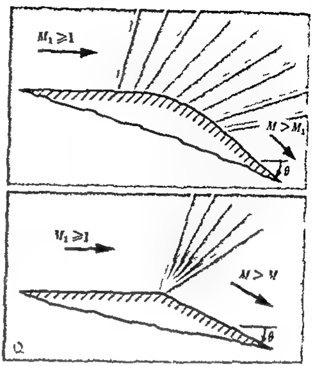
Prandtl Meyer expansion fan

A steady planar compre sible fluid flow that occurs only at super onic speeds The Prandtl Meyer expansion fan is essentially the i entropic flow around a corner from a uniform uper onic flo The illustration shows a typical expansion fan starting from the uniform flow at Mach number M along a flat wall and turning a corner through an angle θ The straight lines in the fan are Mach waves which are standing sound wa es in the fluid The flow behind the fan i al o uniform but the eloc ity is higher and the pre sure i lower A centered Prandtl Meyer expansion fan de elops at a harp corner in a supersonic flow All flo quantities are constant on a gi en Mach wa e in the fan and depend only on M_1 and the angle through which the flo has turned U ing $M = 1$ as a convenient reference the relationship between flow angle θ and local Mach number M is

$$\theta = \sqrt{\frac{\gamma+1}{\gamma-1}}\arctan\sqrt{\frac{\gamma-1}{\gamma+1}}\sqrt{M^2-1} - \arctan\sqrt{M^2-1}$$

The local pressure p is obtained from

$$\frac{p_0}{p} = \left(1 + \frac{\gamma-1}{2}M^2\right)^{\gamma/(\gamma-1)}$$

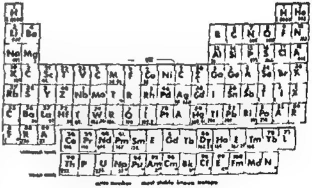


S perso c flow ar u d a cu ve (*a*) p oduc s a fa of stand g so nd wave At a sha p co ner (*b*) the expan on fan is cent r d

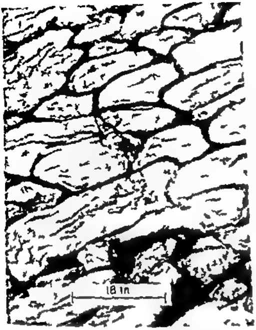
where p_0 is the upstream total pressure and $\gamma = C_p/C$ where C_p = specific heat at constant pressure and C = specific heat at constant volume See FLUID FLOW PRINCIPLES [A E BR]

Praseodymium

Element number 59 praseodymium Pr is a metallic element of the rare earth group The stable isotope 140 91 makes up 100% of the naturally oc



curring element It was discovered by C F Auer von Wel bach in 1885 when he eparated the alts of the so called element didymium into two frac tion praseodymium and neodymium The oxide is a black po der the composition of which arie according to the method of preparati n It is u ually considered to be Pr O11 although if oxidized under a high pressure of oxygen it can approach the composition PrO It can be reduced in hydrogen to give a pale green Pr ■ The oxide PrO i the only form in which it has been clearly demonstrated that pra eodymium exi t in the quadri a



Fg 4 P fl w t et l y f Y ll wk fe G p N h ert T to C d Top f fl w t w d pp l fth h d L gth of homm 18 U F H d G l S rv y C d)

ary g eatly in i t n ty P rt f them s classed A che n a d pa t a P ote zoi

The B lt The Balt Sh ld the nly Pre c mbr a f th h ld l s n Eu ope c cup p t f N y m t f Sw de F l nd a d the K la p n n l f U S S R It o ks di ided by nf m t t th p bly l g ups Th ldest e n ble the ba al fo ma ti f th Can dian Sh eld and a call d Ar h Th y gest ar m I r t th K we n wan a d t a d l f the Lak S p reg n a d a el ed a Prot o c

A a Th P amb n h eld a e f As a ar n S l a d th pe sula f Ind a The sh ld f S be a e kn wn the An ba and Ald n a e Tl a e mp d f f lded Fa ly P mb n sed m t a d g ite r n ded by f mat of Lat P ml a ge In the p ula f Ind the P n h n k b e of th m I r ty t th a l k f the Ca d a Sh eld a alled Ar h f tl v ng r k a lled P r n Th f m ti f th P n g p sep rated f m the A h r Di rw y t m b may f rm ty nd h b nl m d t l def med

Au t Th A t l n Sh ld pie m t of west r a l lf west r A t al It f m t or r i th m j p th lder tw f h h r l ed Ar h a d th th rd Pro t Th P g re mbla f th f th A t al n Ce t al C ldfi ld r g t th P amb a f tl Ca ad n Sh ld h been ted b H F M Kin t

A Tl f P mb n ock Afr that h lve called h ld oc g l h f m the Suez reg on uthward to the Tran vaal In all of this territory ro ks called Basement Archean or Pr miti e y tems are p e ent Late Pr cambrian ro k t which local names ha e l een g en re also repre ented I the Tran aal Precambrian r cks of Protero c age have been intruded by an as emblag of igne us rocks alled the Bu hveld c mplex

South Am rica The Precambrian rocks of S uth America occur ma nly in two exten ive areas known as the Brazilian and Guian an Shields The basal rocks of the Brazilian Shield are largely crystal l ne lime t n and chi t intruded by granite in the Gu anian Shield they consist of lavas schi ts gneis es and g a ite The Late Precambrian rocks n both shields cons st of qua tz te ron formation and ther unf ssiliferou ediments

Mountain areas Precamb ian rocks occur l lly in many f the world mountains Th s type of ccu ren e i w ll exemplified in the cordilleran egi n f North America and th H ghlands of Scotland In th fo mer local ty an utstanding cro s ection of the Precambri n is e po ed n the G and Canyon f the Col r do Ri r where Ar chean s h sts and g anite are o e lain with great un onf mity by the Gra d Canyon Ser es The mo t w d spr ad Pr camb an r ck howev r are the Lat Precamb i n Beltian ed ments which un de li ext nsive a ea in the nt rior f Br t h Columb a and m t of no thern Montan and Idaho Th s o k re d ided by an unc nf m ty nto tw s ri They ha e m x mum th ckne s of ove 60 000 ft

In th Highl nd of S otl nd the on of format n i mpl c ted by p t Precamb ian m u t n bu ld ng nd f ult In the northw t H ghl nd Ea ly P c mbr an t an f rmed ed m nts and igneou g e e f the L w s an Se es lain u co f mably by the l ttle d turbed *Tor d n an* I m r t a d nd t ne pr med t be f Late P camb ian age In the adj cent h ghla d t the so th a the hi hly recrystall zed s d ment of th Mo and Dal ad n S s

[M E W]

B bl g aphy C. O Dunb r *Hi t ical G l gy* 2d ed 1959 H E M K n try P camb i n p b l ms t in Au t ali *Am J S* 243A 448-466 194 T W E Da id *G ology f the C mm alth f Aust l* l 1 1950 M E W l n P camb n el fic t n a d co r lat on with Can d Sh ld *B ll G l Soc Am* 69(6) 57 774 1958

Precast concrete

A n r te t n m nay be c n tru t d by st g th n rete in plac n th ite by bu ld ng it of c mp n t a t el ewher or by a comb n t on of th tw C n t c st in oth r th n its final po i ti n i call d p e t

I ntra t w th ca t pl n te onst uc wh h lum b am gi de a d l bs t ntegrally b ded t g th r f y uc e v p r p t ncr t q s fi ld nn ctions

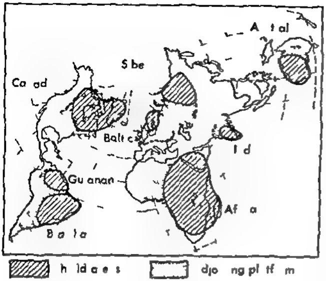


Fig. 2. Shield areas and adjoining platforms composed of Precambrian rock. (*From R. C. Moore, Introduction to Historical Geology, 2d ed., McGraw-Hill, 1958*)

conglomerate is found containing striated and faceted pebbles, cobbles, or boulders up to 5 or even 10 ft in diameter enclosed in a massive unstratified matrix. Such deposits, characteristically derived from glaciers, indicate that the Precambrian climate at least at times was cold (Fig. 1). All of these observations provide evidence that if the earth was originally molten, as most hypotheses of its origin assume, all its original crust must have been destroyed before the existing rocks were formed.

Shield areas. Large relatively stable areas with broad relatively flat surfaces or low topographic relief are characteristic of many Precambrian regions. These areas stood firm or moved differentially upward in contrast to areas of subsidence (Fig. 2).

Canada. The Canadian Shield, the world's largest shield area, occupies most of northeastern Canada, Greenland, the Adirondack region of New York, and the northern parts of Michigan, Wisconsin, and Minnesota. Most of this immense area has been mapped geologically in an approximate lithological way, but the complete succession of formations has been determined only in widely separate local areas. For this reason a tentative classification of the rocks of the shield into two major parts, the Early Precambrian or Archean and the Late Precambrian or Proterozoic, is in the present state of knowledge the only subdivision practicable.

The structural succession of formations has been determined locally in the shield by detailed examination, using the criteria of top determination of sedimentary beds and lava flows. The most important of these criteria are graded bedding in graywacke and pillow tops in lavas. Graded bedding forms in graywacke by the more rapid settlement of coarse particles than fine particles during deposition (Fig. 3). Pillows are believed to originate by the globulation of lava where extruded into water. The slow descent of the globules permits the formation of a rounded pillow top crust before succeeding globules are deposited (Fig. 4). These criteria of top determination combined with the relationships of lavas and sediments to intrusions of igneous rocks make it possible to determine both the succession of formations and their division into separate groups or series by unconformities throughout areas of considerable extent. However, the correlation of rocks across the wide geographical or geological barriers between these areas is less certain. It has become the custom, therefore, to use local names of formations in areas where geological mapping has been most detailed.

The surficial rocks of the Canadian Shield belong mainly to four classes: (1) widely distributed basal lava flows and poorly sorted sediments of the type commonly deposited in the sea adjacent to mountains; (2) crystalline limestone, pure quartzite, shale or slate, completely sorted rocks of the types laid down in the sea adjacent to deeply weathered land of low relief; (3) shale, slate, iron-bearing formation, limestone, and dolomite sediments probably deposited in elongated basins (in places the limestone and dolomite contain concentric structures believed to be of algal origin); (4) interbedded conglomerate, sandstone, and lava flows laid down on land. The rocks of class 1 have been intensely folded and intruded by granite. They belong to the Archean. The strata of classes 3 and 4 lie at the top of the Precambrian succession and have been folded only in places. They belong, therefore, to the Proterozoic. The sedimentary rocks of class 2 have all been mountain built and intruded by granite, but the folding and recrystallization

Fig. 3. Microphotograph of graded bedding in Timiskaming graywacke, Rouyn Township, Western Quebec, Canada. (M. E. Wilson, Geological Survey of Canada)

about th y ax is c lled p ec ssion nd the motion an be pred ted f om the equation

$$M \; i(H + {}_y H - \omega H) + j(H + H - \omega H) + k(H + \omega H_y - \omega H) \quad (1)$$

he e M is the mom t t que abo t the po t O H H and H are the x y and z om p e ts f the a gular m mentum H f the top and i, j and k a e t cto s l n x y and z respecti l Fo th de at n of Eq (1) see RIGID-BODY DYNAMICS

If kS is the p n elocity of the top about the axis ef t e t the x y ord t system the ω_y a d a e th ngular el c ty comp ents f the x, y a d a es wh h ar tta h d t the top at O nd m with t except for this relati e s n

The angular m ment m of the t p s

$$H \; iI_x\omega + jI\omega_y + kI(\omega + S) \quad (1a)$$

h I I I ar the mome t f inertia of the top abo t the x y z a es thr gh O

S b t tion f th s equat n i t Eq (1) (f r st d state m t on $= \omega =$ $- S = 0$) g e

$$M_O = i[\omega(\omega + S)I - \omega_y\omega I] + j[\omega_y\omega I - \omega(\omega + S)I] + k[\omega_y\omega I - \omega_y\omega I] \quad (2)$$

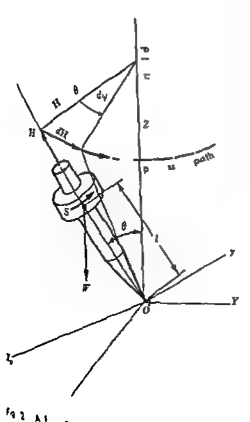


Fig 2 A t p g t p pp rt d t t O p e- cesses bout th 1 Z how

For the case where ω and ω are negligible compared to th spin S Eq (2) becom s

$$M \cong S\omega I \quad (3)$$
$$M \cong -S\omega I \quad (3b)$$
$$M = 0 \quad (3c)$$

For th case ill trat l in F g 1 $M = -Wl$ $M_y = 0$ (m me t due t W about y) and $M = 0$ (f cti nal torque abo t z $S = 0$)

From Eq (3a) fied by experim nt the top slowly precesses abo t the y axis with a p ecessional eloc ty that is co nt cl ckwise wh b erved f m bo e and gi en by

$$\omega = \frac{-Wl}{I_zS} \quad \text{(a stant)} \quad (4)$$

Fr m Eq (3b) $\omega = 0$ d the t p mai t ns t p tion i the h ri o tal pl ne Fr m Eqs (3) one see th t any m ment exerted on the spi n ng body f ut the x axi p oduce an ang l r vel c ty f prece si bout the y axi and any mom nt e ted abo t the y a p d c a n g ti e p e ce i n bout th x xis S ch a pi ning body is the h rt f the gy cope d such moments M d M are lled gy copic m me t

If th top of F g 1 is ow pl ced n the more general pos ti h wn in F g 2 a mila pr es n abo t fi ed rt cal a s (Z) d e to the gra ity m ment w ll esult Thi mo t asily seen by side i g the a gular m me t m ecto H Beca S is ery l ge s c mpa ed t the ngul r l c ty mp nent f the oord t system x y z atta hed to th t p th ect r H i d re ted very nearly along the sp n axi d i gi en by $H \cong kIS$ F om F g 2, the moment ect d to g avity di ect d norm l to th plane of the and Z s at all t mes a d this p d a hange dH t me dt f th a g lar m me t m ector F m Fig 2, $dH = H(\sin\theta)(d\psi)n$ (n = u t v to norm l to pla Z) $dH/dt = H \sin\theta\,(d\psi/dt)n$ a d $M = Wl(\sin\theta)n$ The eq ti f a gula m t n $M = dH/dt$ b c mes $Wl \sin\theta = H \sin\theta\,(d\psi/dt)$ Th ef re

$$\frac{d\psi}{dt} \cong \frac{Wl}{I_zS} \quad (5)$$

th p e l el ty

The q t f m t is sat fied if the a f the t p w g r p e a u d Z w th a e- l city Wl/I_zS nd w th θ the i l ti n f the top t the t l h g d N te that Eq (5) de t l t Eq (4) d f l g sp the p ece small at fy g the mpt f the ly th t the mp f ω a egl gible mp r d to S

Wh the al f S b m mall a d n l g f lfill th q l ty the g l m t f n g t p must be co d ed For th g n eral a th res lt t m ti n ns t of p e es- nd d a gul l ty of th of p lled t t S NUTATIO (ASTRONO Y AND MECH NICS)

tie the structure together The connections can be a major design problem

Form costs are much less with precast concrete because the forms do not have to be supported on falsework in the structure They may be set on the ground in a convenient position Furthermore a thin wall is difficult to concrete if it must be ca t vertically because the concrete has to be placed in the narrow opening at the top of the form Such a wall is easily precast flat on the ground Moreover the large side forms are eliminated and so are the many braces needed to keep a vertical form in place

With some types of precast concrete construction no time is lost in waiting for concrete to gain strength at one level of a structure before the next level can be placed such delays are common with cast in place con truction Frequently the permanent precast units can be used a a working platform which eliminates the need for a temporary deck

Precast units can be standardized Savings can then result from repeated reu e of forms and assembly line production Furthermore high quality can be maintained because of the controls that can be kept on production under plant conditions However there is always the pos ibility that transportation handling and erection costs for the precast units will offset the savings

Floor and roof systems Precast concrete floor and roof systems may be similar to what is generally used for cast in place con truction The components may be bolted together eated on each other or on bracket held by friction de ices prestressed or the reinforcing of adjoining members welded and the gap between them filled with cast in place concrete Al o certain systems peculiar to precast construction may be used

1 I beam type with cast in place or preca t lab
2 Hollow core type joists
3 A embled concrete block type
   a With contact faces between units ground to provide a slight camber to the a embly
   b With contact faces parallel but with a tension in the lower moment bars sufficient to align and hold the as embly together and to provide a slight camber
4 Preca t inverted T beam joists with precast fillers between
5 Integrally preca t lab and T beam joists

Tilt up construction Originally tilt up construction was the name given to a method of precasting walls in which the units were ca t on the ground at the place where they were to be erected then tilted up to the vertical and ancho ed when they had gained sufficient strength Later it became customary to refer to all types of precast wall construction a tilt up construction

Generally the wall is concreted on a ca ting platform Only side forms are needed Sometimes it is advantageous not only for walls but for floor and roof panel as well to cast succes ive units one on top of the other A bond breaking agent is applied to the surface of the casting platform and between succe sive units

Insert usually are cast in the panels to facilitate lifting The preca t units may be lifted with a crane or A frame often equipped with a trong back or frame to di tribute the uplift forces evenly

Lift slab or Youtz Slick method In one type of precast construction for building popularly known as lift slab but ometimes called Youtz Slick after the developers of the method floor and roof lab for a multistory building are ca t on the ground around the columns The labs are ca t one on top of the other with a bond breaking agent between them Jacks atop the columns lift them to their final position where they are anchored [F S M]

Precession

An angular velocity of the axis of pin of a pinning rigid body which arise as a re ult of external torques acting on the body Example are the preces ion of a spinning top the earth (prece ion of the equinoxes) an airplane propeller or a gyro cope Of the e the mo t familiar is undoubtedly the prece sion of the equinoxe n slow change in the direction of orientation of the earth s axi of rotation which re ults in a gradual we tward motion of th equinoxe For a di cu ion of this phenomenon which wa known to the ancient *see* PRECESSION OF EQUINOXES The uniform prece ion of a charged pinning body in a uniform magnetic field is called Larmor prece ion This motion imilar to that of a rapidly spinning top is of great importance in atomic phy ics *See* LARMOR PRECESSION

Motion of a spinning top Preces ion is be t explained by a di cussion of the beha ior of a ymmetrical pinning top or of any rigid body pinning about an axis of symmetry Con ider a t p pinning rapidly about its z axis of symmetry and placed horizontally on a point upport at O (Fig 1) The top will not fall as a re ult of the pull of gravity (its weight W) as might be uppo ed but rather one will observe that the z axis of the top rotate slowly about the vertical y axis while maintaining its position in the horizontal xz plane This rotation

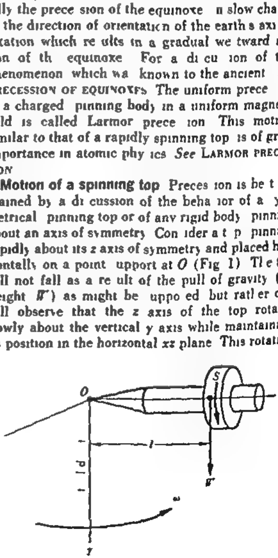


Fig 1 A fa t spin ing top ppo t d at po t O a d relea d o h zo tal pl n p ec ab t th rt cal y a s a show

is t y ax s called prece i and the motion can be predicted from th equati n

$$M_0 = i(\dot{H} + \omega_y H - \omega H) + j(\dot{H} + \omega H - \omega H) + k(\dot{H} + \omega H - \omega_y H) \quad (1)$$

here M is the m ment or t rqu about the point O H H and H are the x y and z c m ponents f the ngular m m ntum H f the t p and i j and k ar unit ector long x y and z respect ly F the deri at n f Eq (1) se R GIDBODY DY AMICS

If W S is the pin eloc t f the t p about the z relat e to the x y oord ate tem then ω_x ω_y a d a the angular veloc ty mpo nt f he x and axes wh ch are att hed t the top at O nd m e with it xcept f thi rel t e spin.

The angular m mentum f the t p is

$$H = iI_x\omega_x + jI_y\omega_y + kI_z(\omega + S) \quad (1a)$$

where I = I I are the m m nt f i ert a f the top about the y xes thr ugh O

Substitution f th equati n int Eq (1) (f r steady state m t n $= \omega_y = \omega = \dot{S} = 0$) gives

$$M_O = i[\omega_y(\omega + S)I - \omega_y\omega_z I] + j[\omega I - \omega(+ S)I] + k[\omega I - \omega_y\omega I] \quad ( )$$

For the ca e where ω ω_y and ω are n glig ll compared t the s n S Eq ( ) bec mes

$$M \simeq S\omega_y I \quad (3a)$$
$$M \cong -S\omega I \quad (3b)$$
$$M = 0 \quad (3\ )$$

For the ca illu trat d in Fig 1 $M = -WI$ $M = 0$ (n mome t du t W about y) and $M = 0$ (n fri t nal t rque about $\dot{S} = 0$)

From Eq (3a) erifi d by experiment th t p l ly preces es bout the y axi wit a pr ces ional el city that is counte lockwi e wh n ol rved fr m abo e and g ven by

$$\omega = \frac{-WI}{I_zS} \quad (\text{a co stant}) \quad (4)$$

Fr m Eq (3b) = 0 a I th t p maintain its po iti n in the h ri nt l pla Fr m Eq (3) one ees that any m ment ex rted n the spinn ng body about the x axi p odu an angular vel city of prec i n about the y ax and any m ment exerted about th y xi produ a n gati pre es ion bo t th x ax Such a p nning body i th heart f th g r c p and s h m ment M and M a alled gyr pic m ment

If the t p f Fig 1 i n w pl ed in th m re g n r l po iti n h wn in F g 2 a s milar p ec n abo ut a fixed v rti al ax (Z) d t the gra ity m ment w ll lt Thi is m t e sily seen b c n d r ng the ngular m mentum ect r H Becau S is ery larg a omp red t the angula elocit mponent of th coo d nate sy t m y atta hed t the t p th ect r H i d r cted ery nea ly al g the spin axis z and i gi en by $H \cong kI_zS$ F om Fig 2, the m ment ect r due to gra ity i directed n rmal to th plane of the z and Z axes at all t mes a d thi pr d c a change dH in tim dt f the g lar m mentum ect r Fr m Fig $dH = H(\ n\,\theta)(d\psi)n$ (n = unit ector n rmal t plan zZ) $dH/dt = H\sin\theta\,(d\psi/dt)n$ nd $M = WI(\ \theta)n$ The e uat n f a gul r m ti n $M = dH/dt$ be mes $WI\,s\,n\,\theta = H\sin\theta\,(d\psi/dt)$ Ther f e

$$\frac{d\psi}{dt} \cong \frac{WI}{I_zS} \quad (5)$$

s th p eces onal el city

The quat f m t o i at sfi d if the axi of th t p w ng p ec rou d Z with a e l ity WI I S nd w th θ the in l nat n f the t p t th ert c l u hang d N t that Eq (5) is ide t l t Eq (4) a d f r la sp n the prec o is m ll tr fy ng th as mpt ons f the a aly th t th mp nts f ω a e negligible c mpar d t S

Wh n the lue f S b c me m ller and n long fulfills th inequal ty the g ral m tion of a pi ing t p m t b c n dered F r the gen al a the r lt nt m t n c n t f pre e n d nd ang lar el c ty f the ax s of p n all d nut t n S NUTATION (ASTRONOMY A D MECHANICS)

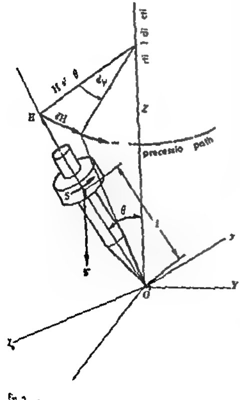


Fig 2 A fa t p g t p pp rt d t g t O p e-cesses ab t the vert l Z_0 a how

to tie the structure together These connections can be a major design problem

Form costs are much less with precast concrete because the forms do not have to be supported on falsework in the structure They may be set on the ground in a convenient position Furthermore a thin wall is difficult to concrete if it must be cast vertically because the concrete has to be placed in the narrow opening at the top of the form Such a wall is easily precast flat on the ground Moreover the large side forms are eliminated and so are the many braces needed to keep a vertical form in place

With some types of precast concrete construction no time is lost in waiting for concrete to gain strength at one level of a structure before the next level can be placed such delays are common with cast in place construction Frequently the permanent precast units can be used as a working platform which eliminates the need for a temporary deck

Precast units can be standardized Savings can then result from repeated reuse of forms and assembly line production Furthermore high quality can be maintained because of the controls that can be kept on production under plant conditions However there is always the possibility that transportation handling and erection costs for the precast units will offset the savings

Floor and roof systems Precast concrete floor and roof systems may be similar to what is generally used for cast in place construction The components may be bolted together seated on each other or on brackets held by friction devices prestressed or the reinforcing of adjoining members welded and the gap between them filled with cast in place concrete Also certain systems peculiar to precast construction may be used

1 I beam type with cast in place or precast slab
2 Hollow core type joists
3 Assembled concrete block type
   a With contact faces between units ground to provide a slight camber to the assembly
   b With contact faces parallel but with a tension in the lower moment bars sufficient to align and hold the assembly together and to provide a slight camber
4 Precast inverted T beam joists with precast fillers between
5 Integrally precast slab and T beam joists

Tilt up construction Originally tilt up construction was the name given to a method of precasting walls in which the units were cast on the ground at the place where they were to be erected then tilted up to the vertical and anchored when they had gained sufficient strength Later it became customary to refer to all type of precast wall construction as tilt up construction

Generally the wall is concreted on a casting platform Only side forms are needed Sometimes it is advantageous not only for walls but for floor and roof panels as well to cast successive units one on top of the other A bond breaking agent is applied to the surface of the casting platform and betwe successive unit

Inserts usually are cast in the panels to facilit lifting The precast units may be lifted with crane or A frame often equipped with a stro back or frame to distribute the uplift for evenly

Lift slab or Youtz Slick method In one type precast construction for buildings popularly kno as lift slab but sometime called Youtz Slick af the developers of the method floor and roof la for a multistory building are cast on the grou around the columns The slabs are cast one on t of the other with a bond breaking agent betwe them Jacks atop the columns lift them to their fi position where they are anchored [F S M

Precession

An angular velocity of the axis of spin of a spinni rigid body which arises as a result of extern torques acting on the body Examples are t precession of a spinning top the earth (precessi of the equinoxes) an airplane propeller or gyroscope Of these the most familiar is undoub edly the precession of the equinoxes a slow chan in the direction of orientation of the earth s axis rotation which results in a gradual westward m tion of the equinoxes For a discussion of th phenomenon which was known to the ancient s PRECESSION OF EQUINOXES The uniform precess of a charged spinning body in a uniform magnet field is called Larmor precession This motio similar to that of a rapidly spinning top is of gre importance in atomic physics *See* LARMOR PRECE SION

Motion of a spinning top Precession is be t e plained by a discussion of the behavior of a sym metrical spinning top or of any rigid body spinnin about an axis of symmetry Consider a top spinnin rapidly about its z axis of symmetry and placed h izontally on a point support at O (Fig 1) The to will not fall as a result of the pull of gravity (i weight W) as might be supposed but rather o will observe that the z axis of the top rotat slowly about the vertical y axis while maintainin its position in the horizontal xz plane This rotatio

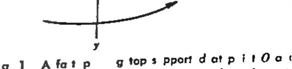
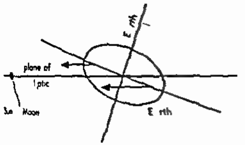
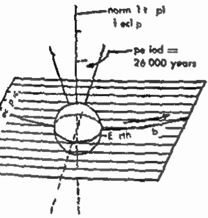


Fig 1 A fa t p g top s pport d at p i t O a r le d a h z t l pl e p ec bo t th rt l y a a how



1 Th gra tat l tt ct of th S m E rth lt m t rq e wh ch t d t t p h



2 Co l t of E rth s O e mpl t le f p q 26 000 y a s.

at cir le in hich the plane of E rth s eq mt ect the el ti l sphere) r (2) th date en su b a r g occurs D ri g its ann l m y ar nd the cl pt c the S n r e th e n l equ to tw ce The e are the efore two equi ne e h year th vernal equi ox occ s ab t rch 21 and the ut mnal equ occ s abo t ember 23 The n al westward mot n f the ui ox cau ed by pre e s on m u t to abo t The ral m tion of E rth a s f n con t of preces i n pl a ec nd ang ar m ion of the a i hich i lled utation For d us of th e phe om n e NUTA (ASTRONOMY AND MECHANICS) PRECESSIO ASTRONOMICAL COORDINATE SYSTEMS EARTH ORBITAL MOTION EQUINOX

Phys cal causes The lu is lar pre es on of the no es u ed by the gra tati nal t o f th S n a d the Moo wh ch a re lt f the f tte ng of Earth a d th i cli at on of Earth axi gi es t mall t ming m ment in qui n th Earth in its orb t (Fig 1) Th s que not co t t be se of the a yi g po n n sp e of th th ee bod e in lved Be of th l er d t nce f th M th m g tude f th t que d e r th M o t tha that d to the S n As result f thi t q e Earth s ax de b e b ut th n rmal t the plane of it orb t (F g 2) th p d f th

prece i n i approximat ly 6 000 y ars in a direc tion op ite t that f Earth s r tati n that i the equin e prece fr m ea t to w t Be au e the angular m mentum of the spi ning Earth is so large th r te f prec i n i extremely sl w

Planetary precession Th i i a comparati ely mall ea twar l mot n f the eq i xes a i ed by the a ti n f the th r planet in alt ring the pl e of Earth orb t Plan tary preces i n al ca i e a m ll ch ang in the rat f l uni la pre es n

Effects A a re ult of pr e i n P lar is w ll n t alway b the pol tar Veg will b n arer to the n rth el tial pole in abo t 12 000 y r α Dra co i w th p le tar abo t 4600 ye r ag An th effect f prec i n i th t the signs of the zodia n l nger c rre p d t their r pect e n tellat Th ign of Ar i n w in the c n t llation of I e and n [K W R]

Bibl g aphy H N Ru ll R S Du gan nd J Q St wart *Ast o my* vol 1 1945

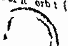
Precious stones

The mat rial f und i n ture that ar u ed fre qu ntly a g m t n including amb er beryl (em erald nd aqu m rine) hry b ryl (cat ye a d l x ndr t) cor l c ru d m (ruby and sap phire) diam nd feld p r (m n t ne and mazon it) gar t (alm ndite demant d and pyr pe) jad (jadeite d n pl t) j t lap s la li mal a hite opal pearl perid t q artz (am thy t cit e and agate) p el sp dumene (kunz te) to paz t urmalin turq o s and rcon S Gem

The term preci and mip ci u h e bee ed t d ffere t te between gem t ne on a b i of elati e alue B au ther i conti uous gr d tion of al s f om mate ial old by the und t tho l ed t ma y th ds of dol lars p r carat and becau e the same min al m y fur h both di n i ent ally mean ngle s All but f w of the gem li ted co t ma y dollars per carat in fi quality G ld the ymbol of con ntrated alu and the mea ur of precio i es b ings le s than $0 25 per arat Thu alm t all m sto es me t the e of the t rm preci us [R T L.]

Precipitation (chemistry)

The pr ces of p od i g a separ bl s l d phas withi a liq d med um In bro d en e precip tat on r p e nts the fo mat o of w co d n ed ph e ltho gh oth te m ar fte u ed t de c b th p o e s Thu (1) a p gas on de ses to l q d d pl ts o more sp ifi ally a in m teorol gy w te apor th atmo ph p e ip t tes t fo m a n sn w or ic (2) a ub t nce n the liquid te freez l d fies (3) a d l ed compo t y tall s fr m a su sat ted s l t (4) a ew l d pha e g dually pre p t te w th s lid all s the ult f a low n chem al react on o (5) metal el t d p t p n th p s ge f a lec t l u e t th o gh a sol t on



Gyroscope motion A gyroscope consists of a rapidly spinning rigid body with an axis of symmetry Generally such a body is mounted in a Cardan s suspension (*see* POINSOT S METHOD) so that its mass center is fixed and set spinning with a large angular velocity Equations (3) are valid and (3a) and (3b) can be expressed as a single vector equation

$$\omega = \frac{1}{I_s S^2}(\mathbf{S} \times \mathbf{M}) \qquad (6)$$

where S has a direction along the axis of spin The precessional angular velocity ω of the axis of spin is always at right angles to z and M Therefore from Eq (6) the axis of spin always turns toward the resultant moment acting on the gyroscope

This simple analysis and result shows the stability which a large rotation imparts to a body because under such rotation the body refuses to change the direction of its axis unless large moments are applied When such moments are applied the resulting displacements due to the precession are obtained according to Eq (6) and are shown in Fig 3 As a result a gyroscope is applicable for stabilizing ships in rolling seas or a monorail car for inertial navigation instruments and as the heart of the gyrocompass Furthermore the dynamical analysis of the gyroscope explains how bullets and shells that are spun obtain aerodynamic stability in flight. *See* BALLISTICS EXTERIOR GYROSCOPE

Airplane maneuvers Rotating masses on aircraft such as propellers gas turbine rotors jet engine compressors and the like can exert gyroscopic moments on the airplane during maneuvers

As an example consider an airplane which is making a sharp turn in a horizontal plane (see Fig

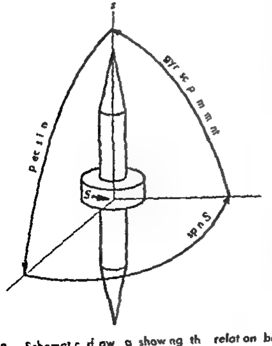


Fig 3 Schematic drawing showing the relation between spin moment and precession of a spinning body

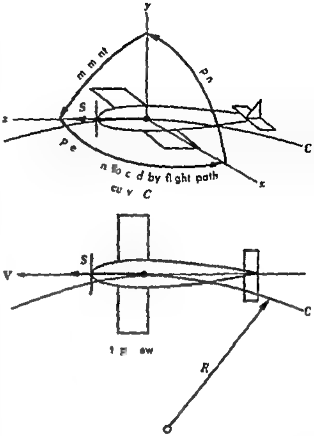


Fig 4 Rotating elements such as a turbine rotor or propeller in an airplane following a curved flight path exert gyroscopic moments as shown

4) As the airplane follows the flight path curve C it is forcing the rotating parts with spin S to precess with velocity $\omega = V/R$ From Eq (3) then the airplane must exert a moment $M = S\omega I$ where I is the moment of inertia about of the rotating parts If the elevators are not set to produce the required moment M the nose of the airplane will rise

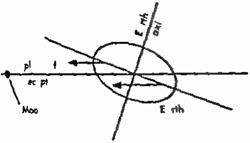
All flight paths which involve sharp and rapid turns and loops will be accompanied by gyroscope moments exerted by the rotating parts although such moments are usually small as compared with the aerodynamic moments acting [R E BO]

Bibliography G Joos *Theoretical Physics* 3d ed 1958 A G Webster *Dynamics of Particles and of Rigid Elastic and Fluid Bodies* 2d ed 1959

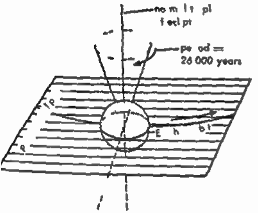
Precession of equinoxes

A slow change in the direction of orientation of Earth s axis of rotation which results in a gradual westward motion of the equinoxes There are two types known as lunisolar precession and planetary precession The total precession is the sum of the two The phenomenon of lunisolar precession which is by far the more important was discovered by Hipparchus about 125 B C and was first explained by Sir Isaac Newton

The term equinox has a dual meaning It refers to (1) either of the two imaginary points at which the ecliptic (the apparent annual path of the Sun among the stars) crosses the celestial equator (the



ig 1 Th g t t l tt t n f th S o loo n E rth lt t q n wh ch t nd to t p rth



'g 2 Co l mot f E rth s O ompl t y l f p q 26 000 y s

It at ci cl wh ch the pl f Ea th s equ o t e t th el sti l phere) ( ) the dat he s h o si g ceu D ring t n u l journ y r d th l pti th S n th e lesti l eq t tw n The a e th I t o eq n es ach y th e nal qu e rs ab t M h 21 d the t m l qu n x bout S ptemb 23 The n ual we tw d m t of th q e u d by p e n mo nt to about 50′27 The gener l m t n of Earth s a s f rotati n o t f p e e n pl a e o d a g la m t on f th a wh h s ll d n tati F r m l di n n of the phe m e NUTATION (STRO OMY A D ME HANICS) PRECESSION S ls ASTRONO IC L COO DIN TE SYSTEMS EAR H O ITAL O OT O EQUINOX

Physical causes Th l n l p ece of th qu ed b th gr t t n l tt a t n f the S d th M whi h a n lt f the p l fl tt g f E rth nd th i l n ti n f Earth i g s t small t m ng m m t, t q th E rth n ts o b t (F g 1) Thi t qu t t t b f the ryi g po t of the th ee bod es ol ed Be f th l d t n f th Moo th m g t d f th to q d e t th Moo g e t than th t d e t th S As a res lt f th t rqu F th d bes ab t th rm l t th pl f it o b t (F g 2) the p iod f th

prece s on is appr ximat ly (000 years in a direc t o ppo it t tl at of Farth rot ti n that t th equinoxe prece fr m ea t t we t Becat e tl angular momentum of the pinning Farth is so large the rate f prece i n i e trem ly slow

Planetary precession Tl i a mparat ely mall ea tw rd m t f the equin x au ed f y the actio of tl e ctler pl net in altering th pl ne of Farth rbit Pla etary pr es n alsc ca s a sm ll hang in th rate of l ni lar pre c

Effects As a re ult f pr ce i n I lars w ll n t always be th pol st r V g will l e n arer t th n rth celest al pole in about 1 000 ye r n Dra c ni was tl e p le tar abo t 4600 year ag An ther ffe t f pr ce i n i that the signs f tl e zod a no l g r corresp d t tl r re pecti e c n tellat n Th sig f Ari i now in the con ll ti of P and o [K W P]

Bibl og aphy H N Ru ell R S D g and J Q Stewart *Ast o my* v l 1 194

Precious stones

The m terial f d in nat re that are u ed fre qu tly as gem t n i clud ng ml r beryl (m ald and aquamarin) h y l ryl (at e) and alex ndr te) c l e r nd m (r by and ap phir) d am d feld p r (moon ton and amazon it) garn t (alm ndite demant id and p r pe) j de (jad te and e l rit) jet l pi la l mal a hite opal pearl pe dot q artz (amethy t cit ne nd ag te) pinel spodum ne (kunzite) to paz, t urmal t rqu and z rcon *See* GEM

Th terms p ec and mipreci h v l e n sed to d ffere ti t betw en gem t n s on a ba i of rel ti e al Be au e there i a c ntinuo grad ti n f al fr m m teri l old by the po d to th al ed t m y tho ands f dol la s per arat a d bec e th ame mine l m y f n h b th a d v t n s tially meaningl All but few f th gems li ted co t ma y d llars p r rat i fine qu l ty G ld the symbol f con ent ted lue nd the me s of preciou ness b i gs l th n $0 25 per c rat Thu almost all gem at es merit th se of the t m pr us [R T L.]

Precipitation (chemistry)

Th p s of p od ng eparable l d ph e with l q d m d um In a b ad en e p t tion p ts th f rm tio f n w co de ed ph alth gh th r t ms are oft n sed to d c ib the p ces Th (1) a ap g s co d n to liqu d d pl t or mo pe fic ll a m t l gy wat vapor n th tm phe pre p t t s t fo m ra n w or i e (2) a sub t e the l q d tat freez s l d fies (3) a d s l d c mp t yst ll es fr m a u at t d l t o (4) n w l d pha e g d lly pr c p t te withi l d all y a the lt of a sl w e chem al r act o (5) a m tal el t dep ts upo the p ge f an l t al rrent th ugh a olut n

In analytical chemistry precipitation is widely used to effect the separation of a solid phase in an aqueous solution. For example, the addition of a water solution of silver nitrate to a water solution of sodium chloride results in the formation of insoluble silver chloride. Quite often one of the components in the solution is thus virtually completely separated in a relatively pure form. It can then be isolated from the solution phase by filtration or centrifugation, and the substance determined by weighing. This procedure is known as gravimetric analysis. Precipitation may also be used merely to effect partial or complete separation of a substance for purposes other than that of gravimetric analysis. Such purposes might involve either the isolation of a relatively pure substance or the removal of undesirable components of the solution.

Solubility product constant. The extent to which a component can be separated from solution can be determined from the solubility product constant obtained by determining the quantity of dissolved substance present in a known amount of saturated solution. This value is known as the solubility. The solubility can be drastically altered merely by adding to the solution any of the ions comprising the precipitate, as for example the addition of varying quantities of either silver nitrate or sodium chloride to a saturated solution of silver chloride. Although solubility can be altered over a wide range, the solubility product itself remains practically constant over this same range.

The solubility product constant can be used to ascertain the quantity of dissolved component remaining unprecipitated in the presence of known concentrations of the ions common to the precipitate. By proper adjustment of the concentration of the added common ion, it is possible to reduce the quantity of dissolved component to a negligible value, although never to zero. It is an extremely important criterion of a method of gravimetric analysis that the quantity of unprecipitated component be negligible, particularly in comparison with the quantity of precipitate formed. The analytical chemist uses the word quantitative to describe such a chemical reaction. *See* SOLUBILITY PRODUCT CONSTANT.

Impurities. The purity of the precipitated solid phase is of major concern, both for the preparation of a desired chemical compound and for a quantitative method of gravimetric analysis. It is not possible for a precipitate to be formed as an absolutely pure compound by chemical reaction within the solution phase. Other soluble substances present in the solution, such as the ions not involved in the structure of the precipitate, tend to accompany the solid phase in varying amounts. This phenomenon is known as coprecipitation. The fraction of the total quantity of such foreign ions coprecipitating may be quite small. Although this fraction depends on experimental variables, it is highly dependent upon the relationship between the solubility characteristics of the desired chemical precipitate and the foreign substance. As a specific example, partial precipitation of iodide (as silver iodide) using silver nitrate would coprecipitate (as silver chloride) only a small fraction of any chloride present, whereas it would coprecipitate (as silver bromide) a larger fraction of any bromide present. The iodide is more insoluble than the bromide, which is more insoluble than the chloride. Knowledge of the relative solubility characteristics of the chemical species present is thus extremely desirable to the chemist who needs to know whether foreign substances are being collected with the solid or are being left in solution.

A precipitated phase may incorporate foreign ions within its structure in several ways. Best understood of these is isomorphous mixed crystal formation. Radium and barium sulfates form isomorphous mixed crystals because the two compounds have the same crystal structure and the ionic radii of radium and barium are not greatly different. Thus radium and barium ions are interchangeable within the crystal lattice to a considerable degree. Silver bromide and silver chloride will also form isomorphous mixed crystals. Because of the ease with which interchange can take place within the crystal lattice, isomorphous mixed crystal systems should be avoided if a good separation of the two different ionic species is desired. On the other hand, the property of isomorphism may also be put to good use in concentrating minute traces. For example, barium sulfate precipitated in the presence of minute traces of radium will carry with it almost all of the radium. Such procedures are frequently used in the collection of minute traces of radioactive species.

An ion present at high dilution may be incorporated apparently by mixed crystal formation even though such formation would not be predicted on the basis of crystallography and ionic radii. An example of this is the coprecipitation of traces of lead with potassium chloride. This phenomenon is known as anomalous mixed crystal formation or isodimorphism.

When foreign ion incorporation cannot be ascribed to isomorphism, coprecipitation may occur by adsorption. Residual charges at the surface of a precipitate attract charged ions in the solution. The adsorption process results in a greater concentration of foreign ions near the precipitate surface than exists in the main body of the solution. Adsorbed foreign ions may remain quite firmly attached to the solid. In fact, they may be covered as succeeding layers of the crystal are deposited and cause imperfections within it. This latter phenomenon is known as occlusion, although it arises as a result of adsorption. The term occlusion should be distinguished from inclusion, which refers to the mechanical trapping of the solution (and solutes in it) within the precipitate.

Sometimes one substance in a mixture precipitates rapidly, but a second foreign substance then precipitates slowly as a second solid phase. This is not generally considered to be coprecipitation

b t r ferred to a po tprec p tat The p t prec p tat of zi c ulfide with copper ulfide i a typ al example

Methods for reducing contamination In an ef f rt t red ce c ntam at n by foreign i n the hem t es rts t rious tech q se Precipita t n f d l t sol t is ofte effect Heating the re ct m t that i dige ting th lid in l qu d pha speeds recry tallizati n proce e by hi h inc por ted f eign io may l e retur ed to the sol ti n phase Prec p tation f m h moge eous sol n, a tech que i which th desired precip tating g nt f med i ternally w th n th sol tio by chemic l synthe i results in the f rm ti of la e cry tal f small rface area, d h n e les coprec pitation

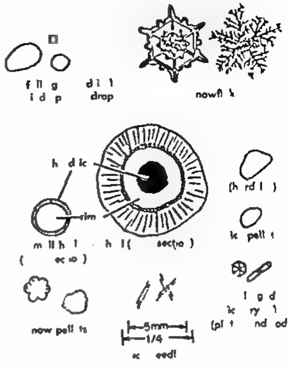
If all these method fa l t educe d quately th qu ntity f f reign i ns i corpor ted i the ld ph then r prec pitat on i applied The p ecip t te is d sol ed and rep ecip t ted by the p s p oced e A in the i it al prec p t ti n a majo f t f th f e gn i w ll ema n i sol tio The p oce f r p ec p tat m t be repeated u til the qu nt ty f f eign i s present n the p ec p tate e be d reg ded S AD ORP TIO CRYSTALLIZATION ELECTRODEPOSITION ANAL YIS GRAVIMETRIC A LYSIS I OMORPHISM (CRYS TALLOGRAPHY) NUCLEATION SATUR TIO OF SOLU TIO S S PARATIO (CHEMICAL A D PHYSICAL) [L.G]

Precipitation (meteorology)

The f ll t f w te dr ps r frozen part cles f om th atm ph e Liqu d types r r drizzl a d fr zen types w h l am ll h l pellet (also c ed e gr n n th Un ted States leet) p llets (gr upel, soft h il) n w gram ic n edles d e cry tals I E gl d leet d fined m t e f rain a d ow m lt ng w D p t f dew f ost, rime, d m t r l lected f m f g e oc ionally lso la sed a p ecip tation. All types lled hyd m teo f h h ddn ll rm l d f g, wet ha e m t, bl wing w d p y Whenever r n d izzl f eezes n c tart w th the gr nd to f rm sol d ting f t lled f ez g r f eez g drizzl o gl zed fr t s l all d an torm glaze t rm, a d somet mes p p larly k as l er thaw err neo ly leet t rm.

M t p e p tat p rt les rry n f r st t h her p t n g t e h r he g f th h g nd t tion to ther pr b lem f tmospheric lect r n r ompler ly u d t od. S A MOSPHER ELE TR ITY TH DERSTO M

Ra w ic p llet m y f ll teadily r h Steady p ec p t m y h term ttent th gh l k g d len l s f nten ty Ha l m ll h l d w p llet o r nly n h wer drizzl gr d y f o a t dy p ec p i wer gl te f m n t b l ty t m l f m ly l er a



Fg 1 V lous f rm f prec p ot

ate dy p ec p tat n c mes f m t atif rm l d Se CLOUD

D pth f a n m lted w oth f rm f p ip tat n m ured at the g nd d i r ferred t a p ec p tat n, p e pit t n am nt or mply r fall Fr zen f rm r fir t m lted t bt i th r w t ntent nd then th am nt ar rec rded n m llimete (mm) n hes and h dredth f l qu d w ter S p at m a urement r mad f the d pth f m lted now ha l n ther f ozen f rm S P E IPITATION GAGES

Liquid types Ra n d d zzle somewh t r b t r ly d ferent ted Ra dr ps ar generally 0.5 mm m d ameter d d ffer fr m d izzl m nly n ha ing l g izes D izzl may also be d t gu hed f m a by th meteor l g c l n d t n f it f rm t dr zzl fall ally f m f g thi k t t l ud wh e r n mes fr m cl f f um l type e l d ext nd ng w ll abo the freezing level. P d p ar rarely l rger th 5 mm n d m ter be a l ger es tend to br k p

The mall r ndr p r app x m tely ph rical l r l g f ll g dr p f ttened (F g 1) esp lly n the l tt m d Th f ll w ng pe d f f ll g d p n meter p r nd w m as r d t ll a r by P C nn (d p d meter e i mm)

Speed	0.27	2.06	4.03	6.49	8.06	8.83
Diameter	0.1	0.5	1.0	2.0	3.0	4.0

Frozen precip tat on. Sn w fl kes ar br ched, x p ar r ry tal rr gul f rms u h a m t r d n edles m tion f both ften they r st d t y r me Th p ed f falling flakes i

variable it is greater when the flakes are rimed and is mostly 1–2 meters/sec *See* SNOW

Hail mostly seen in thunderstorms forms with the aid of warm moist air when clouds build to great heights Hailstones usually have concentric layers of rime and hard ice typically 1 cm in diameter but ranging up to more than 10 cm *See* HAIL

Ice pellets are of hard ice either clear or opaque and may be spherical or irregular Th

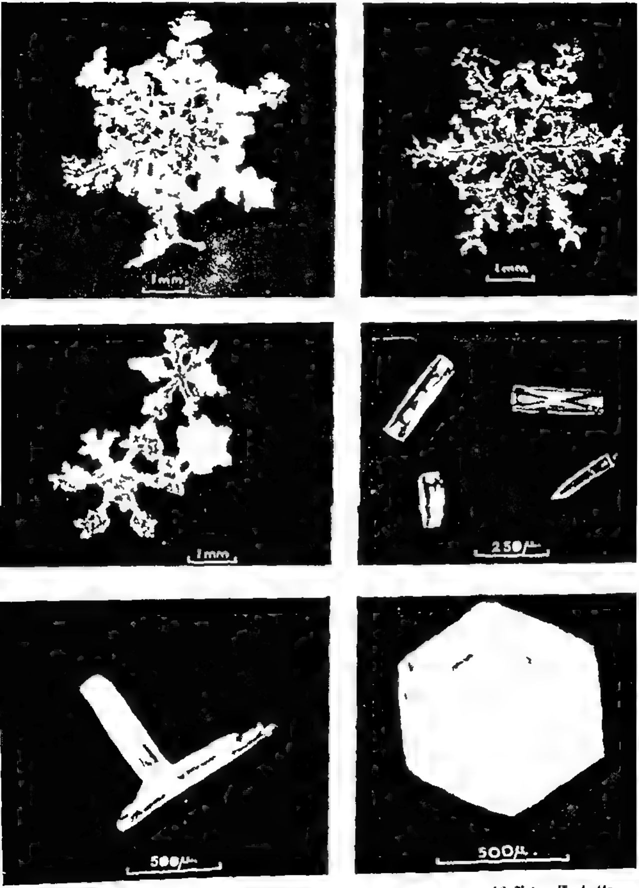
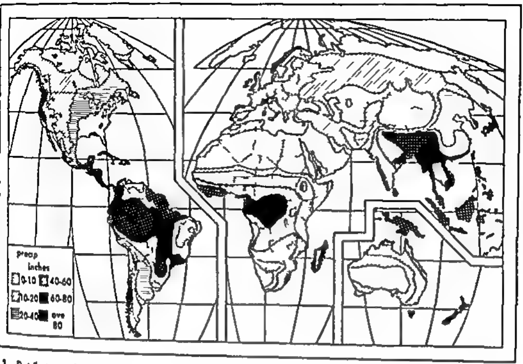


Fig 2 Photograph of snow and ice crystals (a b) Snow flakes (c) Snow flakes and snow pellet (d) Rods (e left) Ice needles (e right) Pl t [illegible] J Ma Snow crystal E d a Oct b



3 D t b t f e g l p ipt t th l d (F m N A B gt d W V Roy F d m t l f E m G g phy 4th d P t e-H ll 1956)

f rmed by th f eezing f ra n r drizzle d p no pell ts are f ft, op q e e irreg l ly ped som t mes with s all ped edges a d often ded with a few blo g r b hed cry tal c l d m te 2 5 mm Th y fall u lly h e s, somet mes ev n when gr und t mpe a s ar a f w degrees abo e f eezi g U Nakaya d the pec fic g ty to be ab t 0 12 S w ns re s m la but maller nd flatt with di t s ar nd l mm o l s they f ll generally n ll amounts f om st atu cl uds fog e edles ar narrow po nt d ryst ls ro ghly mm l g a d ab ut mm n d meter wh ch gly or n lust r m stly t t mper tu e l ttle bel w f eezi g e ry tal a e m ll ds or plates They f ll in tabl a r that oft n w tho t cl ud a d m l ght they ettl t the g d

eographical distribution P e pit t o is p rt n hyd l gic ycle the c nt n u nte cha ge ter b tw n a l d a d atm sphere but its rib tion o e the earth is u ev n (F g 3) om w ld d f ll amou ts a e f l 1.23 in. Un ll Md 1956 1 h 12 00 H lt, Mo 1947 24 h u s 45 99 B gu ppin 1911 2 d ys 65 79 i F kik F a, 1913 31 d y 366 14 i Cherrapu j I d 1 year 1 041 8 i nd 2 y 1 605 05 in Ch rr punj I d 1860–1861 (d ta f m W th B e u)

recip tation and weather P p t t n o r t ft y l ne t opical d t ba I th f eca t g eve l y pt (we the) types f p e p t t n a e g d warm t, rm m t a r g o e w dg f ld c ld f nt cold u de tt g d l ft ng warmer ir on e ti e ca ed by local upd ft f m t a con erg t general l ft g of i ca ed by con erge ce t low lev l and r g aph c m t air f r ed upward mounta lope Any type m y t al ne h wever co tion r c n e ge e may cc r w th the typ Lake w fall when a r at first t emely c ld l l w ff a l ay r ff lakes h as the Gr at Lak Minor cau es of pre ip tat n a e t rl le e t t ling (air m i g e a lder f ce) and nightt me rad ati n f om cl d t p but the yield mall m t

Condensation in the atmosphere Bas ally th equ res th t air b ooled t and bel w it dew poi t Then mi t water d plets f m by o de sat n or i crystal form by sublim ti The d plets or e cry t ls a e cl ud pa ti l from wh ch by a gr wth m cha m the l rger p e ipitat pa ticl may f rm Th o ly cool ng p oces ffi ent t p od e app e able p cipit t n is ad b t c e p s n wh ch occu s i a r ing t w d l wer p ssures Se ATMOSPHERIC DIABATIC CHANGE Th r of nd n ti n in r ing sat ted a i g te the warme the a and i directly p op t l to the speed f a ent F d s u i f co dens t o nu l f m ti n f pre ip t tio in clo d d a tificial st mulat n f p ecipit t n s CLOUD PHYSICS WEATHER MODIFICATION

For d cu ons f ther top cs r l ted to p c p t ti n e DEW DEW POINT FOG HU IDITY HYDROLOGY RAIN SHADOW VAPOR PRESSURE

[J R F]

B bl g phy T F M lone (d) *C mp d um of Met l gy* 1951 S P tt s n *W th l l ysis d F c t g* v l 2 2d d *W th W th Sy t m* 1956

Precipitation gages

Instruments used to measure the amount of rainfall or snowfall expressed as inches or centimeters depth of water which falls on a level surface When precipitation gages are equipped with a recorder the time of occurrence and the rate or intensity are available as well Other forms of precipitation such as dew frost and moisture absorbed by the soil are also of considerable interest but they are not measured by the precipitation gages routinely used by the meteorological services

General design features The gage is basically an open container and funnel constructed to minimize any splashing out and mounted 1–3 ft above the surface to prevent splashing into the container yet not so high that its catch is affected by the wind which normally increases in velocity with height From the volume of water calibrated and the area of the opening the depth of water is easily obtained Various schemes are used to obtain the water volume The U S Weather Bureau calibrates the catch in a cylinder whose area is one tenth that of the gage area The depth is measured by a dip stick calibrated in inches Gages used in other countries have bottles graduated cylinders or other arrangements for obtaining the volume of the catch The funnel in each of these gages reduces water loss by evaporation

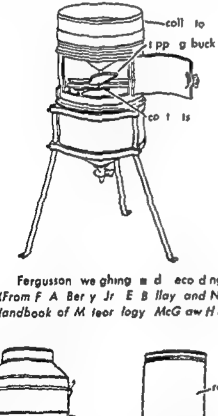


Fig 1 Fergusson weighing and recording type of gage (From F A Berry Jr E B Bollay and N R Beers eds Handbook of Meteorology McGraw Hill 1945)

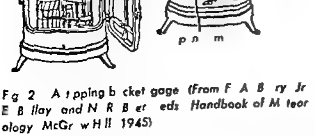


Fig 2 A tipping bucket gage (From F A Berry Jr E B Bollay and N R Beers eds Handbook of Meteorology McGraw Hill 1945)

Recording instruments A continuous type of recording rain gage uses a spring balance to record on a clock driven chart the weight of the precipitation calibrated High sensitivity is obtained by using a slotted linkage so that large amounts of rainfall cause the recorder pen to travel back and forth several times across the chart Another type of recording gage uses a shallow V shaped two-compartment tipping bucket pivoted at the vertex so that it has two stable positions The vertical partition lies just below the opening in the funnel and directs the flow into the other position where the second compartment fills while the first empties into a container Each tip of the bucket corresponds to 0 01 in of rainfall and closes an electrical contact to actuate a remote register Still other types of gage use a float to actuate the recording pen Some of these have an automatic siphon to empty the float chamber when a specific amount of rainfall (0 02 in) is collected

Gaging snowfall When a suitable wind screen is used snowfall can be measured by melting the snow collected in a rain gage (the funnel must be removed) Fallen snow is also measured by taking sample cores A device for measuring the mass of snowfall uses a cobalt 60 γ ray source at ground level columnated toward a Geiger counter mounted several feet above the surface As snow covers the surface the reduction in counting rate as a result of γ ray absorption by the snow is used to determine the mass of snow in the column An attractive feature of the device is that the counts are easily telemetered by radio making it very useful for mountainous regions See SNOW GAGE SNOW SURVEYING [V F S]

Bibliography F A Berry Jr et al (eds) *Handbook of Meteorology* 1945 W E K Middleton *Meteorological Instruments* 3d ed 1953

Precipitin

A term used in serology to describe an antibody that reacts with its corresponding antigen to give a visible precipitate Since precipitin reactions are given by some purified antibody solutions that also give agglutination and other serological reactions this is purely an operational definition Incomplete antibodies are also known that do not precipitate with soluble antigens although they will agglutinate and otherwise add on to particulate antigens and evidence for their occurrence together with precipitating antibody can be obtained for most sera Precipitins may be quantitated by noting the endpoint dilution (titer) of serum required to give a precipitate at the threshold of visibility or the amount of antibody may be determined in milligrams or micrograms by appropriate analysis of the precipitate with correction for the antigen contained

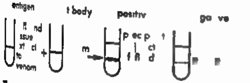
th See ANTIBODY ANTIGEN PRECIPITIN TEST [H P T]

Bbl e phy S Raff l *Immun ty* 1953 G S Wil d A A Mile Topley and Wil n s *Pn. I s of B cter logy and Imm ity* " vols 4th ed., 1955

Precipitin test

A t rm u ed in erol gy t de c ibe a pecific re-act betwee ant ge and tibody that result n vi ble p ecip tat

Th p ecip tin te t or rea t n i a tech iq used in ol gy to determi e eith r the a tigen r its correspo d g antibody Th re cti n d ffer fr m a l t t n ch efly in the ize of p rti les I ed. In ggl t n t the p rti le re u lly ll and are u u lly la ge en ugh to be een nder the mi r op The pr cipiti te t i m t fte ed t t f pa l la a t gen i extract f kn wn ba teri blood t in o ti d it fi d ppl t i the d s f b cterial d eases h s t eptococ l infecti nd a thra and in th med Il g l de t fie t n f th a mal pec es p o id a blood ta n or ti ue The m t important id tifi t on f ntibody i th t re lt



Th g t st f m f th p ipt t t (F m C. J Witt M b logy w th Appl t N ing 2d ed McG w H ll 1956)

ing from syph l t nf ct n alth gh th a t ge utilized may b d ri ed fr m mal well s syphilit t The K hn, Kl ne nd th r floc lation test a e ampl Th p c p t t st may be mit ted b m x g cl r ant ge nd nt body I u and b rvi g wh th r a p e ip t t f rm after h rt peri d at 37 ft h u s r days t 0 C. It m y be qua tit t d by b rvi g th l m t i g dil u n f t body r l d bly th tigen, t h h th r t n b m s ju t i bl Or th am t f p ip t te may be d t rm ned s milligram m r gr ms f p te n by app o-priate h m l strum ntal p c d s Th e m est m te as l ttle a 0 1 μg a t body n tr g th an cc cy f ±10% l the i t the antigen l tu n i l d e m c t g th t b dy p sti t t s de ted by a ble p ec pt t l je t th t f A t gns d a t bod es m y al be perm tt d to diff e t w d on an th thr gh aga g ls th tech q e p m t an l of th mb of c mp e t n c m pl system S AGGLUTINATION REACTION AN-THRAX ANTIB DY AN IGEN LANCE IELD DI-FERENTIATION SCHEME STREPTOCOCCUS [H P T]

B blog phy W C B yd *F d me t l f Im munol gy* 3d d 1956 M Cob and J O d Tech que nd n ly f th q ant t t e p e cipitin reacti n *M thods in M l R earch* 5 301 3 8 1952

Precision approach radar (PAR)

A radar y tem located on a airf ld f r ol rva ti n of th po ti n f an air aft witl re pe t t a appr a h path and p ifically i tended to pro-vide g dan e t th aircraft d ring ti appr h

The PAR sy tem c n i t f a g d radar quipme t wh ch i alternately n ted t tw nte na y t m One f tl e nt na y tems sweep a narr w beam ov r a 0 t r in th e l ri z ntal pl n The ec d nt n a t m weep a narr w b am o er a e t r in th ert al pla e S nce th reflected energy from tl air raft pro-d ces i f rmat n on the l ati n of tl aircraft in t rm of angl a d di ta ce the two w p g e the three-dimen i nal l ati n f the aircr ft (F g 1)

T It in th nec ary d crimin ti n the an t na y t m m t prod c ext em ly narr w beam w dth F rth r nce it i n ces ry t l t n i f rmati n ery ften the te n m t be apal l f can ing at a y f t rate (abo t 4 / ec) The desired p f rma e i l tai ed by i e f lo g linear ray f d p l Ope ti g n a f eq en y f appr xim t ly 10 000 meg y les m of these nt nn a ay ha mpl y d 130 d p l d l ad l ngth f pp x mat ly 8 5 ft The res lt ng b m width f r th ant n a eep ng i the h i nt l pl n i a he ght f bout 1 5 nd w dtl f 0 The nt n weep ing i th rtic l pl ne has a w dth f approxi m tely 3 0 and a h ght f 0 8 (Fig 2) Rap d weeping i a mpl hed ly changi g tl pha ng f the e gy fed t th d p le Thi ph e h s c mpli hed by a yi g th d m n f the wa d h h feed th d p le

Va s p e tat n f the d ta f om tl PAR h be n p oduced On f th ampl t pre nta t n empl y tw c th de r y ll p One f these pr nts zimuth s d ta c th

Fg 1 G d w th p pp h d (F m P C S d H El ct A g t E g g l f t l T l ph d T l g ph C p 1958)

Precipitation gages

Instruments used to measure the amount of rainfall or snowfall expressed as inches or centimeters depth of water which falls on a level surface. When precipitation gages are equipped with a recorder, the time of occurrence and the rate or intensity are available as well. Other forms of precipitation such as dew, frost, and moisture absorbed by the soil are also of considerable interest, but they are not measured by the precipitation gages routinely used by the meteorological services.

General design features. The gage is basically an open container and funnel constructed to minimize any splashing out and mounted 1–3 ft above the surface to prevent splashing into the container, yet not so high that its catch is affected by the wind, *which normally increases in velocity with height.* From the volume of water calibrated and the area of the opening, the depth of water is easily obtained. Various schemes are used to obtain the water volume. The U.S. Weather Bureau calibrates the catch in a cylinder whose area is one tenth that of the gage area. The depth is measured by a dip stick calibrated in inches. Gages used in other countries have bottles, graduated cylinder, or other arrangements for obtaining the volume of the catch. The funnel in each of these gages reduces water loss by evaporation.

Fig. 1. Fergusson weighing and recording type of gage. (*From F. A. Berry, Jr., E. Bollay, and N. R. Beers, eds., Handbook of Meteorology, McGraw-Hill, 1945*)

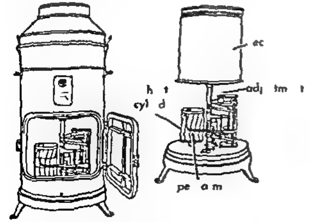


Fig. 2. A tipping bucket gage. (*From F. A. Berry, Jr., E. Bollay, and N. R. Beers, eds., Handbook of Meteorology, McGraw-Hill, 1945*)

Recording instruments. *A continuous type of* recording rain gage uses a spring balance to record on a clock-driven chart the weight of the precipitation calibrated. High sensitivity is obtained by using a slotted linkage so that large amounts of rainfall cause the recorder pen to travel back and forth several times across the chart. Another type of recording gage uses a shallow V-shaped two-compartment tipping bucket pivoted at the vertex so that it has two stable positions. The vertical partition lies just below the opening in the funnel *and directs the flow into the other position,* where the second compartment fills while the first empties into a container. Each tip of the bucket corresponds to 0.01 in. of rainfall and closes an electrical contact to actuate a remote register. Still other types of gages use a float to actuate the recording pen. Some of these have an automatic siphon to *empty the float chamber when a specific amount of* rainfall (0.02 in.) is collected.

Gaging snowfall. When a suitable wind screen is used, snowfall can be measured by melting the snow collected in a rain gage (the funnel must be removed). Fallen snow is also measured by taking sample cores. A device for measuring the mass of snowfall uses a cobalt-60 γ-ray source at ground level collimated toward a Geiger counter mounted several feet above the surface. As snow covers the surface, the reduction in counting rate *as a result of γ-ray absorption by the snow is used to determine the mass of snow in the column.* An attractive feature of the device is that the counts are easily telemetered by radio, making it very useful for mountainous regions. *See* SNOW GAGE; SNOW SURVEYING. [V.E.S.]

Bibliography. F. A. Berry, Jr., et al. (eds.), *Handbook of Meteorology,* 1945; W. E. K. Middleton, *Meteorological Instruments,* 3d ed., 1953.

Precipitin

A term used in serology to describe an antibody that reacts with its corresponding antigen to give a visible precipitate. Since precipitin reactions are given by some purified antibody solutions that also give agglutination and other serological reactions, this is purely an operational definition. Incomplete antibodies are also known that do not precipitate with soluble antigens although they will agglutinate and otherwise add on to particulate antigen, and evidence for their occurrence together with precipitating antibody can be obtained for most sera. Pre*cipitins may be quantitated* by noting the endpoint dilution (titer) of serum required to give a precipitate at the threshold of visibility, or the amount of antibody may be determined in milligram or microgram *by appropriate analysis of the precip*itate, with correction for the antigen contained

utio of the terus lies ju t beneath th anteri r b m g s

Change in the b ts beg n early in pregnancy th enl rgement and te derne s being comm term ppr che the nipples and areolae se n e and deepen n p gment tion re-cting the pr lifer tio of the gla d lar element the b ea t A watery r lightly turbid di ge alled l tr m may be expres ed f om e nipple espec lly i women wh h e had p gn ces

Changes in the v g na ar es and cervix ac mps p g e si n f preg ancy Sy temic h ti n i renal funct n d o e lar ad pta blood v me nd ell c unt as well a in hem al c t tuents f blood a d ti ue all r flect he co pl phy l gi change req r d for f p eens cy

Ectopic and multiple pregnancy Ect p c preg y necu h n the fertili ed ovum bec me im lanted n t s e other than the dom t i m of h t rus Th s id to h ppen in about 1 out er 300 p n nci and mo t f th e ab rr nt mpl nt t n s f u d in the F ll pian t bes Other tes f impla tat on re the o a ies and th bd al c ty

Mult ple pregn ncy i d c tes th s multane u d e pm t f two r m re fetu e Twi oc ur be t in 90 pregnancies triplet nce n 10 00 and gre te numbe s a e unu al eno igh t be f h alded eve ts

Term nat on of pregnancy Pregnanc e m y proceed t term o m y be c nclud d by natur l r art fi l m a p t to normal d li ery The term abort on s used to di at the p ag of a fet s les th n 1000 grams n b f re the twenty-e ghth eek of pregna cy Thi may cu sp nta eously as a esult f a y ne of many cau e b t un fortun t ly t l-o f q ently occu as the re ult f l duct on

Wh n p gn ncy is term t d fter th tw nty ghth w ek a d bef re the e d f n mal pr g n y p m t e nf t s bo n Premat l b r m nly f ll tes i f t n m ltipl pr g ncy p m t e ruptu e of the fetal m mbran s d th r pecific nd n spe ifi e ents Ab ut f ll p egn nc s nd i p m tu lab r Th f nt m t l ty de r ase with the l gth of p g ncy a d th ize f th f t

Alth gh the no m l per d of pregna y m n g 280 days f m th begi n g f th l t m t u l per d 269 days f m the app t m f f rt l zat n m c mplet ly cu thod ts f th s m a em nt Th ase h h gna y h e t ed f 300 d o l g w th n ly ab rm l fe tur s nth f p g

[E C S T]

Pregnancy disorders of

Th lat e mm n m n mpl nts f n us a m t g fat gu d tipat n a d ls the m e n u d rd m nt d he

Perniciou v miting is u ually fou d early in pregnancy Its cau e i unkn wn l it appropriate treatment i u ually succe f l

Th t x mi s f pregn ncy are a gr up f d ea e f und in the la t trime ter or foll wing de li ery They are haracterized by hyperten i n albuminuri and edema Th e nvul ion and coma of eclamp ia may en ue if tr atment i d layed

Chr nic hyp rten io heart di ase and chron c kidney di ea e re pree i ting cond ti n whi h produc h gh perc nt g of c mpl cati n du ri g a d after pregn n y

Am g the inf ct di ea e tuberculosi and syph li pre ent hazard t b th m th er and th e un born infant Alth ugh form rly a dre d d killer childbirth f r (puerpe al sep) a tr pt cal infe ti n ha largely been el m nated in mod rn faciliti b t till x ts in backw rd area Se Streptococcus Syphilis Tuberculosis

Hem lyt c di ea e e pab le of pr d icing e re damage t the red bl od c ll f ither the m th er r child may b e largely a oided or at le t antic ipated by p oper blood testi g P rtic lar tten tio i g en t the Rh fact r a d imilar genetic blood g up S Blood group

Hemorrhage in pr gnan y ma b e due to m ny c u e b t f y f r th m t c mm n t al rtion le c mm au e re e t pi pregnancy p e mat ure l b r nd premature eparation of the pla ent f m the uter

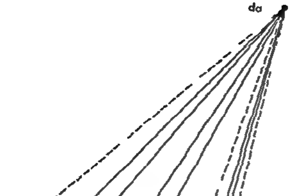
E ect p c pregna cy a n t i frequent cur ren e a fertilized ovum becomes implanted in a ti ue ther th n the uterine mu M t often th ite of implant ti n is s me part of the F llo-pi tube which become tretched nd inflamed as gr wth p ocede uptur is not uncomm In oth r a s the f rtilized m may be implanted on ome p rt f the pe t neum or m ntery and prod c me ympt m if g wth p oc eds There are ca ional epo ts of the deli ery f full t rm n rmal inf nt by abdom nal operat on fr m u h a ite In mo t ca e howe er it i bel ved th t th mbryo doe n t survi e a d is gradually b d b the b dy

It i timat d th t of ry 100 fert liz t on nly 70% ll develop into term infants Of the emai de th d re bn rm l th t implanta ti n an t u one th rd re ult in bnormal embryos which are ab rted a d o e th rd are lo t by sp nt n o s abortio f m other cau S e Fertilization

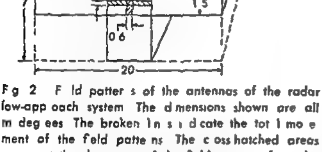
[E C S T]

Prehnite

A m n l l at omp it on $Ca_2Al_2Si_3O_{10}(OH)_2$ y tall zi n the rth rhombic sy tem D t t cry tal a e are a d it occur u ually n e f rm nd t l tu ggreg t s w th cry t ll ne rf H dn i 6-6½ Moh ale pe fic g a t s 2.8-2.9 It h s a it e luster w th a l ght g e n t white ol r Pr hn te is ch ra t i ti lly f u d l ng the ca t in b salt r ks



F g 2 F ld patter s of the antennas of the radar low-app oach system The d mensions shown are all in deg ees The broken l n s i d cate the tot l mo e ment of the feld patte ns The c oss hatched areas ep esent the d mens on of the feld patte ns from the antennas when they o e not swe p ng



F g 3 S mple d spl y of a low-approach rad (a) A im th-d st nc (b) El vat on-d stance

other ele ation versus di tance (see Fig 3) The operator positions transparent pla tic cales over the spots representing the target Attached to the scales are cam mechani ms that rotate voltage di viders The cams are cut with curves that corre spond to the localizer and glide slope positions that an aircraft should follow in making an opti mum approach With an aircraft making an opti mum approach the cams always po ition the arm on the voltage divider o that the output is zero Deviation above or below or to the right or the left of the optimum path produces a po iti e or nega ti e output voltage This voltage is connected to a cro pointer in trument such as that u ed with ILS See INSTRUMENT LANDING SYSTEM (ILS)

Probably the mo t elaborate PAR presentation is that known as the AZ-EL cope On this oscillo- cope pre entation all information i generated electr nically The upper half of the o cillo cope is devoted to the pre entation of glide lope (ver cal position) indication and the lower half of tl scope is devoted to azimuth (localizer) indic tion The optimum paths in the horizontal and ve tical planes are indicated by electronically gene ated line Di tance is displayed logarithmically that about half of the scale shows a distance equ to 3 miles while the remaining half is equal about 7 miles

It is not necessary to have specific airborr equipment in order to utilize the PAR sy tem a though such equipment has been used experimei tally In common practice the ground PAR oper tors call instructions to the pilot indicating th relative position of the aircraft with respect to th optimum approach path or give the pilot maneuvei ing instructions that will bring the aircraft to th approach path See AIRCRAFT LOW APPROACH SYS TEMS NAVIGATION SYSTEMS ELECTRONIC [P C S

Bibliography P C Sandretto *Electronic Av gation Engineering* 1958

Pregnancy

In humans the period of about 280 days required for the normal intrauterine development of a child Fertilization or conception occurs if shortly after ovulation a male sperm penetrates the ovum Ovulation is usually midway between men trual periods The o um pas es into the Fallopian tube and then into the uterus Most fertilization is be- lieved to occur in the tube within a day or o of ovulation If the fertilized ovum does not proceed into the uterus one form of ectopic or displaced pregnancy may occur See FERTILIZATION OVUM SPERM CELL

Under normal conditions the fertilized ovum will pass into the uterine cavity and become implanted in the lining or mucosa called the endometrium This highly vascular tis ue which usually re pond to the cyclic regulation of female hormone now gradually comes under the influence of the ge ta tional or placental hormones The e tend to main tain the muco a instead of allowing it to be loughed off periodically In addition they directly and indirectly exert influences on the entire en docrine system o that almost e ery ti sue and organ of the body is affected See PLACENTATION

As the embryo de elops rapid differentiation of germ layers into organs and systems occurs ac companied by a corresponding growth in the size of the embryo and of the supporting placenta

Maternal changes Changes in the mother are most marked in the reproductive organs including the uterus itself A slight e largement an l soften ing of the uterus may be detectable on examinati n by the end of the econd month A further enlarge ment occurs the mu cular wall l ecome hypertro- phied and then tretched o tl at it is soft and me what flexible During the fourth m ntl tl e ut r ordinarily ri es abo e the pel i and becom abdominal By the end of pregnancy the upper

Pressure measurement

The d terminati n of the magn tude f a (fluid) f rce ppl ed t un t area

Pres ure mea urements are ge erally cl fied ga e pres re ab lute pressure Gage pressure the d fference bet ee a gi en pre ure a d the pres m f the atmo phere Ab lute pre re is the t t l pres ure luding that f th atmos phere Atm ph press re was the fi t pre ure that m really mes ed it remain a imp tant third teg ry Press es le ll n atmospheri pre ure e called v cuum (*see* VACUUM MEA URE MENT)

The t ble c mpa es e ght c mm n unit f pre ure m a em nt. To a d conf n ab o- lu o g ge fte s ffi ed f r e mple 100 pound p r quare ch g ge pres e (100 p g) ll po d pe q are inch absol te pres re (ll ps)

I th l bo t ry pressure is n imp rtant measurem t, s the pres e level h s a ig ificant effect o mo t phys cal ch mi al a d biol g l proces s.

I ind try—p rt cula ly in th pr ess i du tries—p s m a ured nd ntr lled t main t unif rm ty f pr d t, to guide i fe p n, t d term p mping he d f r fl d tr fe d to m u e other a able i d ectly incl d ing ght, l qu d level t mp r tur flow and d ity f fl ds, a d hydraul c f r es

P e g ge ge e ally fall i ne f f r categ ries b ed the p i c ple of p at l q d l mn bell i tr m ts expa ibl elem nt f ges nd el ctric l p e et a d ce

Liquid-column gage Thi type f p es e g ge in l des b omete nd m n mete It co ts f a L h ped t b p rtly filled w th a ol t le l qu d. W te a d me c ry re th two mo t com m liquid sed th type f g ge *S* BAROM ETER MA OMETER

If leg l ft ope t the atmo phe th d eren e in level i a d ct me u f g ge p e. If tw p s e t b c mp red i applied to h leg f th g g The l el es in th l p n leg nd d p in the h gh p ess l g Th d ffe t al pr n the dif f en in lev l (h d) m lt pl ed by the de ty f th trum t l q d

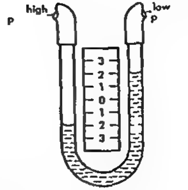


Fig 1 liq d-c l m g g (U t b m om te)

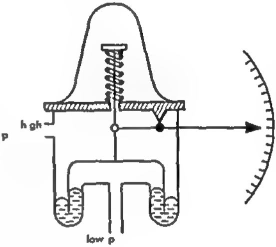


Fig 2 B ll typ g g

Bell type gage Th c ts f a h i g i whi h a bell p n d wnwa d is p rt lly imm r ed i liq d ch l ght l r mere ry The liquid t as l betw n p sur appl ed n ne sid f the bell and the atm ph e o th th r id V tic l moti f th bell pp ed by a c l b ted led w e p g i a d ect mea ur f g ge p ur

The b ll typ g ge c al be empl y d to mea th d ffere betw n tw kn w p es r s B th s d f th bell e e l ed d mot of th bell d tected a d mea ed th gh p e

Pressure eq ivalents

	tm	kg/ m	psi	Hg	H O†	mm Hg	mb	μ Hg
Atmospheres	1	1 033	14 70	29 9	406 8	760	1013	
Kilogram pe squa ce t m t	0 96 8	1	14 22	8 96	393 7	73 6	980 7	
P d pe squ h	0 0680	0 0703	1	2 036	27 68	51 71	68 9	
Inches f m ry	0 0334	0 0345	0 491	1	13 60	25 40	33 86	
Inches f ate †	0 00 46	0 00 4	0 0361	0 0736	1	1 868	2 486	
Mill eters f mercury	0 0013	0 00136	0 0193	0 0394	0 53	1	1 333	1000
Millibars		0 0010	0 0145	0 0 95	0 401	0 750	1	7 0 1
Microns f m cury						0 001	0 00133	1

At 32°F (0 C) to co t to H t 60 F mult ply by 1 00 83
† At 39 2°F (4 C)

pectolite Noted localities in the United States are at *Patterson and Bergen Hill New Jersey West*field Massachusetts and Farmington Connecticut *See* SILICATE MINERALS [C S HU]

Press fit

A press fit has negative allowance that is the bore in the fitted member is smaller than the shaft which is pressed into the bore Tight fits have slight negative allowance so that light pressure is required to assemble the parts they are used for gears pulleys cranks and rocker arms *Medium* force fits have somewhat greater negative allowance and require considerable pressure for assembly they are used for fastening locomotive wheels car wheels and motor armatures *See* ALLOWANCE FORCE FIT SHRINK FIT [P H B]

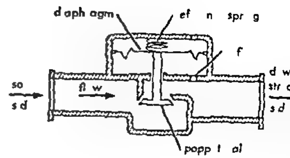
Pressure

The ratio of force to area The force per unit area at the interior of the Sun is estimated to be 3×10 dyne/cm In interstellar space pressure approaches zero Atmospheric pressure at the surface of Earth is in the vicinity of 14 lb/in Pressures in enclosed containers less than this value are spoken of as vacuum pressures for example the vacuum pressure inside a cathode ray tube is 10 mm of Hg meaning that the pressure is equal to the pressure that would be produced by a column of mercury with no force acting above it that is 10^{8} millimeters high This is absolute pressure measured above zero pressure as a reference level Inside a steam boiler the pressure may be 800 lb/in or higher Such pressure measured above *atmospheric pressure as a reference level is gage* pressure designated psig *See* MILLIBAR [F H R]

Pressure control automatic

A form of feedback control system in which the controlled variable is the magnitude of the pressure of a fluid In many chemical and petrochemical processes maintenance of a pressure or vacuum is an important condition to successful operation Pressure control is used not only to obtain a satisfactory reaction but also to obtain constant flow through a control valve or constriction when the main pressure source is variable The *configuration of a pressure control system is* closed loop that is the controlled pressure is measured and compared to some reference or set point The difference between the set point and the actual pressure reading causes an actuator to open a valve The valve admits more or less fluid thereby increasing or decreasing the pressure at the point of measurement until a balance is reached Some of the more complex systems adjust pressure by varying the speed of a pump or by decreasing pumping efficiency but most use throttling method The same general principles which apply to the design and performance of all dynamical feed*back control* systems apply to pressure control systems

The automatic pressure control systems require transducers that measure the pressure and



Pressure regulating valve

convert the reading into some readily usable form such as force torque rotation displacement electric voltage or current *Once converted into a usable form* the signal is processed in a controller and *applied to an actuator which varies the pressure* adjusting mechanism

Pressure control systems have many possible forms A common mechanical form is the reducing or regulating valve which combines the functions of the pressure transducer controller and actuator in the simple device shown in the figure The controlled pressure on the downstream side is adjusted by opening or closing a poppet valve which throttles the flow of fluid As the valve is adjusted the controlled pressure falls or rises The poppet valve may be regarded as the actuator in a feedback control system

The reference input is the force created by the compression of the spring This force is compared to the force created by the pressure on the diaphragm and if an unbalance exists will open or shut the valve depending on whether the pressure *force is lower or higher than the spring force* As in all feedback control system the possibility of self induced oscillation exists This would occur if change in valve area were too large for the error in pressure Oscillation is prevented by restricting the feedback passage An orifice in combination with the volume of the diaphragm cavity acts as a low pass low gain element This element performs *the functions of a controller in preventing oscilla*tion and producing satisfactory performance in the presence of disturbances

The automatic pressure control system illustrated in this example is a simple one in which the various *functions of pressure sensing error com*putation controlling and actuation are carried out in a compact device Simpler devices such as pressure relief valve *which exhaust fluid into the at*mosphere or overflow sump or more complex systems using pressure transducers conventional pneumatic or electric controller and separate actuators are also used depending on the application

The basic theory which describes the performance and design of pressure control systems is *identical to that of any dynamical feedback con*trol system Consideration of stability steady state accuracy sensitivity to extraneous disturbances such as temperature and supply pressure and response to random fluctuation are important *See* CONTROL SYSTEMS PROCESS CONTROL [J R R]

Pressure transducer

A instrument component wh ch detects a fluid pres ur and produces a electrical ig al related t the pres re Se TRAN DUCER

In ge eral, the complet i strument sy tem com prises a p es u e ing eleme t uch as a bou d tube b ll or d aphragm element a de ice h h n erts m tion or force produced by th sen i g el m t to a change of an electric l par ter and an i d cating or record g in tru t. F eq tl the in trume t i u d in an auto-matic t ol loop t m ta a desi ed p e ure S PRE SURE CONTROL, AUTO IATIC

Electri al me surement of p e ure m y be pre ferred t mecha al p e matic measureme t f a umber of rea o s (1) Electricity permit tran mis io f signal longer d stanc (2) Som t m s lectricity permits m re accu te r er p d m surem t (3) It i usually ea r r t m t h an el tr l gnal (4) Electricity al y be eco mi lly or functi ally most c n en ient.

P e tra duce may be cl s fied by th p-erati g pri ciple s res t e tran du e strain g ge magnet tran d rs cry tal tran duce d p c ti t nsd e s

Resistive pressure transducers Pre u e is asured by these t a d cers by el m nt that hanges its el tr l i ta as a fu ct of p ess e

Most types of res st e p es ur tra d er u e a ov ble o t ct p ti ed by th pr e e ing l m nt Th mo t mm f rm is a cont ct hich l g a c t s r t r which may be traight re o nd or nm tal ch as car b If th r s cti n f th re i t st t th h ge in es ta ce w ll be p p t l t the m ti f th c nt ct The c o ction may be m d on if rm to gi a nonl e r relation be twee m t n d h e fr ista e

Th res t el ment m y b curved part f a r f n e i n m g angular mo-ti

F gur 1 h w n typ of t e press re tr d r A b llows oppo ed by p ely de gned p i g s s th p e ur d erts the p es t h a m ti n f th plat b tween th bell d the pri g Th pl te bea c

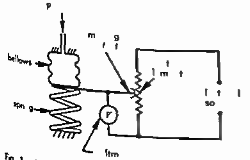


Fig 1 R t p t d

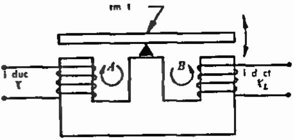


Fig 2 R l cto typ p e s t d c

tact wh ch w pes the surfa e of the preci i n wire w und re tor If a con tant p tenti l (ac r dc) is mainta ed acr s the re i t r and if th r i t an e of the ltmeter high with respect to the r i t r the me ured voltage is a p eci e measure f the pre u e In trument of thi type are avail able with ra ge low 0–5 p nds p r sq i re inch (p i) and a high 0–10 000 p Accuracy f ½% f full s ale i attain l le

Th carb n pile may be ider d t l e an ther f rm of re i ti e p e ure tran d er The s mple t f rm is the a rbon m roph e con i ti g of a box f arb n parti le c ed with a d apl ragm V rying pr ure the d aphragm varie th tact area of the carbon part le hence th ele tric l re i t ce a r s the box The a b micro-phone i u ed only f r dyn m mea urements (h ge) d has calib ted accur cy A m d f ati sing a tack of proces ed d ks in place f the c rbon pa t cle i much m re t bl See MICROPHONE

Pre s re sen ti e wi i set an ther w y of m ring p e ur When fl d pre re is appl ed to a w e the w re i mp e ed a d th r t ce rea e Gold ch mium d manganin wire r o d arily ed be a e they h e un ally low temp ture fficients f resi ta e Pres ures high as 200 000 p i an be measured with th se tra duce

Strain gage pressure transducers The e m ght be idered t be r ti e transducers b t are u lly cl fi d ep tely

St g g p e su t a d cer co e t a ph i l d plac m t int a ele tri al ignal by use f the f ct th t when a w i tretched t diam ter d crea d nd t le t al re i ce i ed Th hang n e t e me s e of the d spl ment h f the p u e It d ant g i l de fi te re l ti d mall e Th t g g u ally ed i Wheat t ne typ b idge it F a m e omplet d cu n s S R IN G CE

Magnetic pressure transducers I th typ ch ge of p t d to ch ge of mag t l tance r indu t nce wh n o pa t of magn tic ci t is m ed by pre re-g l m nt—b u d n t b bell w o d a ph gm M g etic t nsducer m y attai n y of 0 1% f f ll l

R l ta c type p ss re t sd c r Thi typ p d ces i a m gn t c ci c it a h nge f m g

sure tight bearing or seal The accuracy of a bell type gage is about 1% of full scale

Expansible metallic element gages These are in wide use throughout industry due to their low cost and freedom from the operational limitations of liquid gages

There are three classes bourdon diaphragm and bellows All forms—as single elements—are affected by variations in external (atmospheric) pressure and hence are generally used as gage elements Accuracies vary from 0 1–2 0% of full scale depending on material de ign and precision of components

These elements may be designed to produce either motion or force under applied pressure The more common motion type may directly position the pointer of a concentric indicating gage position a linkage to operate a recording pen or pneumatic relaying system to convert the measurement into a pneumatic signal or position an electrical tran ducer to convert to an electrical signal

Bourdon spring gages in which pressure acts on a shaped flattened elastic tube are by far the most widely used type of instrument for pressures from 15 to 100 000 psi These gages are simple rugged and inexpen ive *See* BOURDON SPRING PRESSURE GAGE

In diaphragm element gages pressure applied to one or more contoured diaphragm disks acts

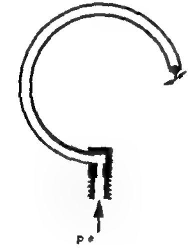


Fig 3 Bourdon tube

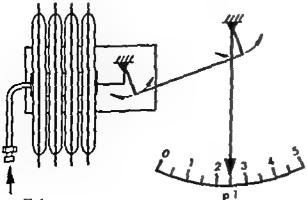


Fig 4 Diaphragm-element gage

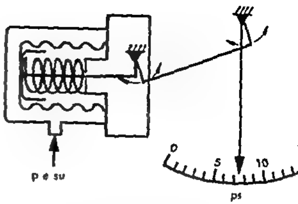


Fig 5 Bellows-element gage

against a spring or against the pring rate of t diaphragms producing a measurable motion T size number and thickness of the disks determi the range from 2 in of water to 30 psig

For lower pressures slack membrane diaphrag are u ed oppo ed by a calibration spring the instrument can detect differential pre sures as lo as 0 01 in of water

In bellows element gages pre sure in or arou the bellows moves the end plate of the bellov against a calibrated spring producing a measur ble motion

Electrical pressure transducers The e devic convert a pressure to an electrical signal The are used for applications requiring unu ually hig speed of response high sensitivity extremely hig or low pressure measurement or for applica tions where an electrical signal repre enting pre sure is more convenient to use than a mechanic motion repre enting pressure *See* PRESSURE TRANS DUCER STRAIN GAGE

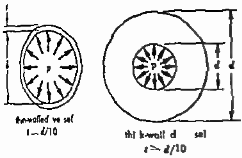
Measurement standards For pressures belo 20 psig the universally accepted standard of pres sure measurement—both in the laboratory and i the industrial plant—is the classic manometer us ing mercury or water

For higher pressures the standard is the dead weight tester The principle is the balance of th force exerted by a precisely known weight on a piston of precisely measured area against a varia ble hydraulic pressure

The pre sure gage which is to be checked o calibrated is connected to the hydraulic reservoir Weights corresponding to the check pres ure are placed on the piston The pi ton and weights are rotated to reduce the effect of friction Hydraulic pressure is increased When the de ired check pre sure i reached the measuring piston floats freely

The dead weight tester is often u ed as a primary tandard for laboratory u e and secondary stand ards (test gage which ha e been calibrated again t the dead weight tester) are used a field or plant te t instruments Dead weight equipment is pro duced having accuracy to within 1/10 of 1% of read ing *See* INSTRUMENTATION PHYSICAL MEASURE MENT [B D H H C P]

Bibliography D M Considine (ed) *Process Instruments and Controls Handbook* 1957



Pressure f f m d te d f h gh p u

ders, So p es re es el m t arry high pres ures, h w r d the thi kne f the l f m t n reas to all w ad q te trength H d aul nd p eum t c cyli ders a e m chine ements th t ar f rms f pre e e ls

Fabri ati n method d p d up the ve el d t N w ll th kn and the typ f cyli de end e pl yed F e t eme tr ngth hea y f rg ay be welded together f m t n rmal e ses, rolled heet a d f rmed nds are fastened to ether w th r

Sh ll stres in pre su e es l is f rther depend upo the typ of d c truction f the yli d o el whether welded ieted ca t th k nd f m t r l wheth d ct l or br ttle and the o d s of p at on ncl ding p e ure d temp t r var at ons nd l m t t n In boo g th s le allow ble tre th e ables are d ed

Alth ugh m t pres re ses ls nta an inter al p es ure, ceas n lly n e t nal p e e is appl d h h f e c s e e uld b ckle the sides a d d f th el S ch cond ti ns dep nd n the la t ty f the m t ial nd e lt bu kl g u d r t l pre s a manne sim lar t the nt al l ad n e l mn S COLUMN

Design Thin w ll d pre re es els s umed t h s un f rm st e s s th o gh the wall h kn s t l the d amet r d s 10 mo e time s g t F pre u p the h ll t e s a n xim m in the umf re t l d e t d thi stre h th lue $s = pd/2t$ I th x l di ti tr t a e ar h lf a g t

Th k ll d p e r e l b n hyp rb l r ss d trib t n thr gh the w ll th k if the d met l than 10 time the th k w th th ma mum st at th i d e rf The

$$s_{(\ \ )} = \frac{p(d\ \ + d^2)}{(d^2 - d^2)}$$

h d is th t d d d th i d d am t S HIGH PRESSURE PROCESSES [J J R]

Prestressed concrete

Con th t e e d ed ii b f e t t unt t tr th t ll be p odu d b l ads.

Pre tre s i mo t effe ti e with c n r t wh h i weak in t n on wh n th tre e ind ed are compr i n One way t pr duce comp ve pre- t e i t place a concrete m mber l tween two al tment with jack between it en l and the l tm nt a d to apply pre ure will the jack A the way by far the m t c mm n i t tretch t l lars o wires a lled tend ns, and anchor them t ll n ret when they try t regain their i it al length d tl e n ete resi t th y pre tre the c r t The tend n may be stretched with jack r l y l at ng (l tri lly)

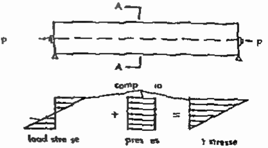
Pre tr ed con rete i parti l rly ad antageou f r l e m It permit teel t l e l at tre al tim l ger th n th permit d for r in forci g l ar It p mit high trength rete to l e u ed ec n m ally f in le igning n eml r with re nf rced c ncr t ll r te l l w the ne tral x i on i lered t l e ten i a d cracked a d th r f in ff cti e whe e the f ll r ecti n f a i r t e el n ncrete l eam i effecti e in bending S e CONCRETE BEAM

An espec lly d ir lle charact i tic f pre- tre d crete i tl t a l ng a th m terial i maintai ed mp e i n it can t c ack If crack h ld ppear nder m ll erl ad tl y g e all will cl wh the l ad i rem ed S m t me n te is pre tre ed p cipally t pre t crack ing

Basic principles Th ffe t f c mpre e p e tre may l e l k ed t p k g up a gr up f l k by apply g pre e t tl e e d pai As l g as th p ure i la ge en ugh one of the book w ll lip out

If thi n pt wer appl d t c n ret b am in a t al p ecti e te l tend would l e t i ed a d pla ed al g the e tr d l of the beam Th e lt g p tre wo ld r lt i a f m mpr s te ery t n (F g 1) Load would prod e b t l t n le a d mpr i e tr e at the m ddle of the pa Th pre t w ld c m b ne with th t in a e th compre i n d l o t the t i n The wh le o cr te ect on w ld be ff ti e i t ting bending and the e w ld b k

In practi howe er t nd s ar r ely placed long th e t id l x s A malle p e t e g f r e s q ed d the f r le s teel f r the tend s if the teel is pl ced b low th ce troidal



Fg 1 St t t AA f b m w th f m p t

netic reluctance which is directly related to pressure. The change of reluctance is usually within one or two coils wound intimately about the magnetic material in the magnetic circuit.

A representative ratio type reluctance changing device is shown in Fig. 2. A bourdon tube or other pressure sensing device rotates the armature.

The reluctances (difficulty of passage of magnetic flux) in the magnetic paths *A* and *B* are determined chiefly by the lengths of the air gaps between the armature and the core. The inductance and inductive reactance of each winding depend on the reluctance in its magnetic path.

If the armature is at a neutral symmetrical position, the air gaps are equal, and the inductive reactances X_{LA} and X_{LB} are equal. Change of pressure decreases one air gap and increases the other, thus changing the ratio of the inductive reactances X_{LA} and X_{LB}. These changes can be used in a variety of circuits to produce an electrical signal which is a measure of pressure. The signal is transmitted to a measuring or controlling instrument.

Inductive type pressure transducer. A change in inductance and inductive reactance of one or more windings is produced by the movement of a magnetic core that is positioned by a bourdon tube or other pressure sensing element. Unlike the action of a reluctance type transducer, the inductance change is caused by a change in air gap within the winding rather than in a relatively remote portion of the magnetic circuit.

Figure 3 shows a representative ratio type inductive device. The pressure sensing element moves the core in response to changes of pressure. When the core is in a central position, the inductances of the two coils are equal. When pressure change moves the core, the ratio of the two inductances is changed. Energy is supplied to the coils by the same bridge circuit that measures the ratio of inductances. *See* INDUCTANCE BRIDGE.

Figure 4 shows another form of inductive pressure transducer, a differential transformer. A change of pressure moves the core, changing the coupling and the ratio of inductance of the two secondary windings.

When the core is centered, equal voltages are induced in the two oppositely wound windings and the output voltage is zero. Change of pressure moves the core, increasing the voltage induced in one secondary and decreasing the voltage induced in the other. The change in output (differential) voltage is thus a measure of the pressure.

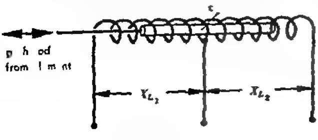


Fig. 3. Inductive pressure transducer.

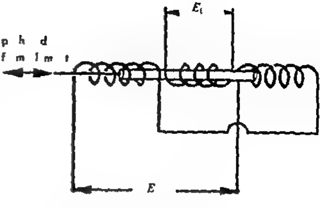


Fig. 4. Differential transformer.

Crystal pressure transducers. A crystal produces an electric potential when placed under stress by a pressure-sensing element. The stress must be carefully oriented with respect to a specific axis of the crystal.

Suitable crystals include naturally occurring quartz and tourmaline and synthetic crystals such as Rochelle salts and barium titanate. The natural crystals are more rugged and less subject to drift of calibration. Although the synthetic crystals offer much higher voltage output, an amplifier is almost always required.

Crystal transducers offer a high speed of response, up to 1 000 000 cps. They are widely used for dynamic pressure measurements in such applications as ballistics and engine pressures. *See* PIEZOELECTRIC CRYSTAL.

Capacitive pressure transducers. Almost invariably these sense pressure by means of a metallic diaphragm, which is also used as one plate of a capacitor. Any variation in pressure changes the distance between the diaphragm and the other plate, thereby changing the electrical capacitance of the system. The change in capacitance can be used to modify the amplitude or the frequency of an electrical signal.

Transducers of this type are available to measure pressures as low as one millionth of one psi and as high as 10 000 psi with accuracies of ½% attainable. *See* PRESSURE MEASUREMENT; TRANSDUCER, UNDERWATER. [B.D.H.; H.C.P.]

Bibliography. D. M. Considine (ed.), *Process Instruments and Controls Handbook*, 1957.

Pressure vessel

A cylindrical or spherical metal container capable of withstanding pressures exerted by the material enclosed. Pressure vessels are important because many liquids and gases must be stored under high pressure. Special emphasis is placed upon the strength of the vessel to prevent explosion as a result of rupture, which would be dangerous to life and property. Codes for the safety of such vessels have been developed that specify the design of the container for specified conditions.

Construction. *Most pressure vessels are required* to carry only low pressure, and thus are constructed of tubes and sheets rolled to form cylin-

encasement in sheaths The con rete i pla ed in the beam f rms a ound the heathed tendons and all ed t et. Whe it has ga ned suff ci nt strength jacks a e us d t ten i n the t nd ns and m so d ing th jacks rea t again t the end f the be.m. The te dons then are anchored to the con crete to pply the p e tre

Freque tly grout is f rced int th sheath to tabl h bond with th beam concrete Thi es the p estres ed beam greater re erve strength and better r k c ntr l u d r overl ad Po ttension ng ppear t be m t adv ntageou for long pan beam d for a mbl ng pre a t b am compo ne ts m th field

Circular prestress C rcular tank pipe the ring girde of d mes may be prestr ed in ntr t to the lin a p e t e ng u ed for be m by wrapp g with t el ba s or w re und r high ten sion (TA K) Special mach es ha e been de l ped for rapid rcul r p e tre s ng with wi e See REINFORCED CO CRETE [T.S.M.]

Bibl g phy Y Guy *P st e s d Co ete* 1953 A F rendant *Pr st e ed C nc et St uc ture* 195 K. Pre ton *P e t ess d Conc t* 1960

Priapuloidea

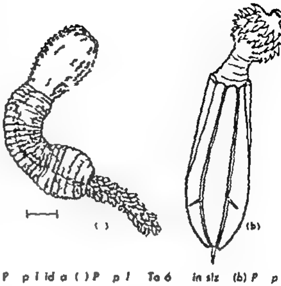
One of the m n gr p of w rml ke animals Once linked th the Ech uroid a nd the Sipun l id under the term Gephyr a now regarded as a sep t ph l m f the animal k ngdom w th uncertain zoolo ical affi tie

P pul dea a e marine an m ls inhabiti g the colder aters of both hemi pher Th y l m burr li ed with mucus in the s d r mud f the ea fl a d nge f om the intertidal a ea t at rs of mod r te depths

The phylum a mall ne with only two gener *Priapulus* and *Hal yptus* In the f rme ther re f ur kn n sp *P aud t* a d *P bi audatus* h h c in the n th n t mpe te z ne nd ar u ws s, *P tube c lato sp sus* from Ant arc. t, and *P h rridus* from coa t of Uru guay There i but on spe ies of *H l yptus* *H pino* found in n rthern wate s *P c dat* and *P t b r ulat p us* are ry cl s ly ll d d ha bee c ider d by ome auth r t b the ame pe es n d t ll tr t th phe m n of b pol ity the n me giv t the o u r c f the same o sim lar sp n Arct c a d Ant r t c t s. With th except n of *P h dus* Pr p l dea a fa ly mm n the r ati e hab tat

They r m ll to med um zed an mals th largest specim ns be g o ly me 6 in i le gth The body i cyl drical d th t u k nulated but not gmented Th b dy f *P pul* m de up f th ee d t n t p rt on the p b tru k a d audal append ge Th latte c si t of o two stems thickly b et w th t bules *H l ryp tus* has no aud l app nd ge

The body wall th ck nd m lar in ll spe c es nd be r nume ou sp nes and pap ll e There are 25 r ws f es on the urlace f the p oboscis l ad g to the mouth which



P p l id a ( ) P p l To 6 in siz (b) P p l l rva

unded by a numl r f oml like teeth Th phar ynx ret a tile and it elf i b et with teeth It i c ntr lled by a ser e f retra t r mu cles atta hed to the in er wall f the trunk Th larva al o p e a tra t le pr b i arm d w th teeth and i protected by h t n us h eld The exe are usu lly epa t Se ANIMAL KINGDOM [A.C.S.]

B bl g phy F Balt e *Ech u ida* in W Ku kenthal and T Krumbach *Ha db h de Zoolog* ol 2 1931 K Lang Über die Entw cklung n *Pr apulus c ud t L m Kgl Fy i g f S ll kap Lu d F rh* 9(7) 80–87 1939

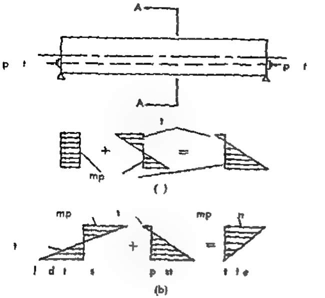
Prilling

A ombin t on spray dry ng nd cry talliz g tech n qu u ed t prod e aggl merate (prill) f ammo m nitr te f r fert l z In prilling a hot on entr ted lutio of ammon um n trate is prayed i t a tow in wh h t crystalli es as it de ce ds thr gh a ri ing current of atmo pheric a r S e CRYSTALLIZATIO DRYING

Primary battery

An le tr c b tte y d s gn d to d li e only o r term tte t d ch rge It cannot be re ha ged ffic entl Pr ma y batte es are de g ed t d l er l mited am nts f el tr en gy d t rm ned by th m ter als u d and th i e f th ll Whe the ailabl energy d ps to e o th b ttery i su lly d s rded Pr mary bat te es may be cla sified by the type f el ctr lyt u ed

Aqueous electrolyte batteries The e batter e a lut n f d h es s lts in wat r as the elect lyte Th s lutio s ha on c ndu t i t e f th rder of 1 mho/cm nd p a t lly n electro c c nducti ity P ctical cells u h th c mmo Le l nche dry ell nd the m rcu y cell e aqueous el ctr lytes They ha e the di d an tages of be g c rr si e to th el ctr d mate i ls



F g 2 Stresses at sectio A A of a beam with eccen tric p est s (a) In the unload d b am the s mple-bend ng stress compone t is largely counte acted by the un fo m compress on compone t (b) When a load i appl ed all tens on components a e counteracted and only compression ema n

axis of the beam With the eccentric prestress stres es at each section of the unloaded beam may vary from tension at the top to compre sion at the bottom (Fig 2)

When loads are applied to the beam they pro duce both tensile and compre sive stre ses at the middle of the span At the top of the beam they cau e compressive stres es which are reduced by the ten ile pre tress there Elsewhere the tensile stresses produced by the loads are counteracted by the compressive pre tress

With this arrangement of the tendons there i a possibility that near the ends of the beam the ten sile prestres may exceed the compressive stre es produced by the loads The net tension may be undesirable even though very small To avoid this condition the tendons may be draped in a vertical curve (Fig 3) The di tribution of prestress at any ection of a beam o prestres ed is similar to that for straight tendons applying an eccentric prestress except that the tres s decrea e from midspan toward the end as do the bending tre es due to the loads The draped arrangement of the tendons al o is ad antageous in counteracting diagonal ten ion near the end of the beam

Continuou beams may be pre tres ed in a simi lar manner The tendons may be placed near the bottom of the beam near mid pan and near the top over upport

Tendons Tendons generally are made of high strength steel o that they can serve at high work ing tre s —for bars about 80 000 p i and for wires well over 100 000 p i compared with the 20 000 psi or le ordinarily permitted for rein forcing teel

Tendon mu t be ten ioned to high stres es be fore being anchored to the concrete becau lo ses in tress due to shrinkage and pla tic flo concrete are relatively high If the tendo ten ioned to only 20 000 psi for examp might lose nearly all the pre tre s in a few But at 100 000 p i tension the lo s might about 15% becau e th increa e in tre not proportional to the increa e in prestre

Creep or plastic flow of concrete or te inela tic deformation dependent on time sulting solely from tre s Concrete hrinl it dries and chemical change take place I is dependent on time but not on tres es external loading In the ab ence of pecific i tion the loss of prestre s due to hrinkag tendons are anchored to the concrete thr the length of a member before shrinkage ha place may be as umed to be 0 0002 in 6000 psi for teel with a modulus of ela t 30 000 000 When tendons are anchored concrete after it has cured for everal da prestress lo s due to shrinkage may be abo psi The lo s due to creep of the concrete a sumed as 2 25 times the elastic compres i CREEP OF MATERIALS

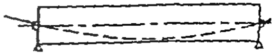
Other possible los es in prestre s that h con idered include those due to creep of th and to friction when the tendons rub agai concrete See PLASTIC DEFORMATION OF META

Wires are used for pre tre ing much mo quently than bars becau e of their greater t They may be u ed singly in pair in cabl po ed of everal parallel wire or in strand may be tretched by electric heating but by most common method of ten ioning is with Various de ices are u ed for gripping or anc tendons including aged fittings on threads on bars wedges and buttonhead on

Pretensioning and posttensioning Two ods are u ed in fabricating pre tre ed bea one method the concrete is bonded to the st steel before the pre tress is applied This i preten ioning In the other method po tten i the prestre s is applied initially through e chorages and the concrete may or may i bonded to the teel

In pretensioning the steel is laid throu beam forms and stretched between external ments Next concrete is placed in the form allowed to et When it has gained su strength the external pull on the tendons le ed tran ferring the prestre to the co through bond Suitable for ma pr ducti method can be u ed on ca ting bed e era dred feet long to produce many beam imu ously

In po tten ioning the ten ons are prev from bonding initially to the concrete u ual



F g 3 Beam w th te do d ped i a ertical

The int rnal es t ce f th e ll i h gh and i re ses t mpe at r decre This h gh nternal res l m ts the ful of the cell but it may be suitable for l g life p tenti l ources f t es

Fused electrolyte batteries Th e u e cry tal lin salts o b h ch a e olid at r m tempera ture. In u e th cell is heated and ma tained at a temperatur abo e the melt g poi t f the elec trol te S RESERVE BATTERY [S F I]

Primates

An ord r f mammals that i cludes the tree shre t rsiers monk ys ape a d ma Alth t gh unqu st n bl n t r l a m l ge th Primate are d fficult t h racter e l rgely bec e they have o n p uo s m rph l g cal pecial ti n p ble to th se ch racters g the bat the h le, th e rni o es a d m st ther ders of m l S ch pec l z ti s a e a ociated with th expl tat on of p rt cul r col gical on (for example, fl ng w mmi g and predati n) and it is evid nt that th Primates e not elo ely t d to n ecol gical zo e r m t the rd of mammal Thro gho t pr mate hi t y ther has been a tre d t w d dapt ti l arbore l l f b t pe h ps m st s g fica t wa the t nde y t emph ize the b n

Fossil record of lower primates The m t prim th e l g p m t the t ee h ews re known from th fo ll eco d b a ngle pec men f gol g b s s f m the ea ly Ol g c e f M g l a. The tree h w t k pp r tly ne e r hed Eur pe th Ame c nd l ing tre shrews a e onfi ed t uth a tern As the E t I des d the Ph l pp n s

Prim tes fi t app i th f l e d n the P leoce d bo t 14 gen a f l m n kn wn fr m th P leoce nd E e f N rth Am n a and E r pe All b l ng n th famil es Pl d p d e a d Ad p dae wh ch di ppea f m th rec d b f e th d f the E c n The best k n f the ly l m s s N tha ct s n m mal abo t th ize f c t f wh ch e l om pl t k l t n t N th t s w ry s mila to th prim t e ex t g l m r f M d g car Lemur d pp d fr m th N rth H mi phe e l d th d f th E e but re b nd ntly rep es ted in th l g f f M d g c r

A soc t d w th thes early lem w o d prim t tock the Anapt m ph d gr p of tar d that u d t t d n ry d pti e d at du i g th P l d E e Th l ury i th l g ta r of th Ea t I d e d Ph l pp es

The l rise nd gal g w l g i uth t m A d Af ic p t c lly known fos l nd th h t ry bs u All r h ghly per lized noct rnal mal w ll ff the ma n li f primat ev l t n

Fossil record of higher primates F ls f the high primates xt em ly ra e p rt c l ly f m th Eoc n nd Ol g e wh th e a m l were pre umal ly underg ing th e r major radiati n C n equently relation hip am ng the h gher pri mat mu t be largely inferred fr m th toms and di tribution f exi ting f rms It i certain that the ance try f the S th Amer n prim te ha been li t ct from that f the Old W rld primat s at lea t i ce the early Eo ene but the a ce t r f neithe group are k wn The l ing f rm are di ided into three perf milie th e Ceboid Cercop theco dea and H mi dea

The Cebo dea (N w W rld m key) are d s tingui hed b hav g three prem lar i tead of t o a i th th r tw gr p Tw di tin t fami l es ar repre nted the C llitrichida (q rrel m nkey) with claw hap d nail and n p p l le th mb a d th Ceb da w th flat nails and an opp al l thumb

Th Cerc p the dea (Old W rld m nkeys) in clude the baboon g ien n and langur f A ia and Afri a

The H m ide (ap and man) form a n tur l g p united by mult tude f c mm feature The great ap (gor lla or ngutan and himpan z e) are ob i u ly relict f rm on the way t xtin t n The g bl maller and m re wid ly d t ibuted ar till flour hing S EUTHERIA PRI ATES (FO IL) ZOOGEOGRAPHY [D D D]

Primates (fossil)

The der P im t u ally ncl de the tupa id lemurid lori es galago tar d m key pe and m n Th t p i d ar m tim pl ed w th the men typhl n i ti an In e l t toward th l gher prim te tur l electi n t nded t f o th e w th larger b ai b tter s ght and m re d xter fr nt f t th t fun tio ed h nd The nci s are ed d to tw i ea h f th j w i the m key nd pe Se PRI ATES

Sm ll pr mi pr mate wer comm n n the middle lat tude of North Am ica a d Eu pe fr m th Pal en ntil the m ddle Eocene Ap pa e tly fa l i t ch ge b tw e th two re g w g eatly red d ce ed d i g the m ddl E e The ar d ty i e ed i the l te E ce d ly Olig ce the d t ibut f th p im te h ft d uthw d n both hemi ph r S m f the p m we e xt mely l e t pr m ti sto k f other order such as th I t a d th Derm pt a E n i the g up that we e ely p m t s i f a d n l af fi t e e ob c ed by th pr en e f b th lemu r d nd t rs d ch a t s

P m t b th R ent nd m ddl a d l te Ce o- e ther r lt f e te i d e ifi t o nd l t n i l ttle k wn p p l t ns that t ded t f m ld l mate n lowe l tit de

True l mu ar fi d t M dag r wh they c n l te Ple i en d p t a d a l i g a mal The o ly f s l of l ri s n t th f m th Pl e of Ind S me elle t g lag f il l e b e f d i M c n fa n K ya t rn Af ca It ha b en s gge ted th t th an tr l t th l i g g l g s Alth gh

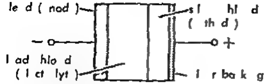


Fig 1 Sol d-elect olyte cell with sol d crystall ne salt electrolyte

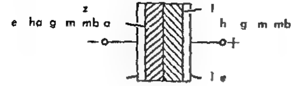


Fig 2 Ion exchange b metall c cell w th sol d elec trolyte

vapor which can cause cell failure and being difficult to make free from leakage For examples of cells with aqueous electrolytes *see* DRY CELL MERCURY BATTERY WET CELL

Solid electrolyte batteries These u e electrolytes of solid crystalline salts whi h have predominantly ionic conductivity The conductivity is small *compared with aqueous electrolytes and the cur*rent output is of the order of 10 amp/in [5]

Solid electrolyte batteries may be clas ified in two broad categories (1) cells with olid crystal line salt such as silver iodide as the electrolyte (2) cells with ion exchange membrane as the electrolyte In either category the conductivity must be nearly 100% ionic Any electronic conductivity causes a continuous discharge of the cell and will limit the stand or shelf life

A typical cell with olid crystalline alt elec*trolyte is the lead–lead chloride–silver chloride* cell in Fig 1 Here lead is the anode lead chloride is the electrolyte and il er chloride is the cathode This cell has a potential of 0 49 volt During dis charg lead ■ oxidized to lead ion and sil er chloride is redu ed to silver

*Cells with solid alt electrolyte have been de*veloped into miniature batterie One type delivers 90–100 volts at 10 amp and has a capacity of 1 amp sec This i over 10 days at 10⁻ amp The practical life of the cell is much le s but may be as much as 10 years at room temperature It can be stored at *160 F for at least 30 days and will* operate over the range −65 to +165 F The battery is ¾ in in diameter 1 in in length

An example of a cell with ion exchange membrane as electrolyte is the zinc–zinc ion exchange membrane il er ion exchange membrane–sil er cell hown in Fig 2 Physically the metal elec trode are in contact with the olid membrane which contains two region The region adjacent to the zinc is in the zinc ion tate The region ad jacent to the il er i in the ilver ion state The di charg reaction increa ■ the zinc ion quantity and decrea es the sil er ion quantity in proportion to the amount of charge tran ferred This cell has a potential of about 1 5 volt

The zinc silver cell de cribed has erious hor comings The tand life is poor indicating interna elf di charge and the capacity is limited by th available upply of silver ions In strongly ionize types of ion exchange mat rial the volume den it of ionizing sites is about 1 equiv/liter or 0 amp hr/in This is very low compared with metal oxide cathodes

*A cell with higher capacity can be made by re*placing the ilver ion exchange material and ilve by manganese dioxide plated on an inert metal such as tantalum This gives a capacity of abou 100 times as much for equal volume

Ion exchange electrolytes are al o u ed with hydrogen and oxygen ga electrodes The electrode consist of platinized metal creens The electrolyte is a hydrogen ion exchange material The room temperature emf of this cell is 0 96 volt *See* ION PERMEABLE MEMBRANE

Waxy electrolyte batteries The e u ■ waxy materials such as polyethylene glycol in which a small amount of a salt ■ di olved in the molten wax At room temperatures the ■ material are solid The conductivity is mall and the current output is limited to about 10 amp/in

Figure 4 hows a battery tack of cells u ing a waxy electrolyte The electrodes are heet zinc and manganese dioxide The electrolyte is made of polyethylene glycol in which is dis olved a mall amount of zinc chloride This electrolyte is melted and painted on a paper sheet to form the separator ing Fig 4

A 25 cell stack built as shown in Fig 4 and measuring 0 34 in in length and 0 25 in in diam eter weighed 1 5 g A 0 50 in diameter tack weighed 6 0 g The initial open circuit voltage wa *37 5 volts (1 5 volts per cell)*

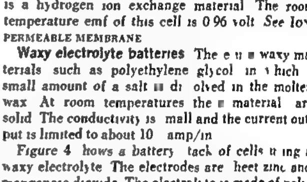


Fig 3 Sol d-el ct olyte cell w th ■ e change mem b an as electrolyt

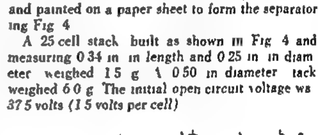


Fig 4 Waxy-elect olyte batt ry stack

Th u cnal re tance of thi cell i high a d s m re ses m t mperature decrea e Th s high m rnal es t n e l mits the u eful f the cell but it ma be suitable fo l ng life p tential ures of min at e

Fused electrolyte batteries The e e cry t l lir salts ba es hi h are l d at r om tempe a ture I n e th ll is he ted a d ma nt ned at a temp r tu e abo e the melting point f the elec rol t S RE ERVE BATTERY [S EI]

Primates

As de of m mm ls that i clud tl e t ee hrews tars s m nkey apes d man Alth ugh ung est bly a natural a emblage the Primat are d ffi lt t h s te iz l rgely l ecau e th y have n co pi ou mo ph l g al pecializat par bl t th e cha cterizing the bat the h l th e mr o es a d most ther orders of m m l S ch sp cial zat ns a e a ciated with h erpl tati f ps t c la ecol gical ones (f r example fly ng imm ng a d pr dati) and it is end nt that the P mates are not o clo ly tied to a ec l g cal z ne as a e mo t tl er order f mammal Th gh ut p imate hi t ry the e h been trend to ard ad pt ti n f arb real life b t p hap m t ign ficant w s th te deney to empha ze the b n

Fossil record of lower primates The m st prim m h ng prim t s the tree h ew re known fr m the f il record by ngle pecimen fr m le gob e s f m the ea ly Ol g ce e f M l s The tree h ew to k pp r tly ne r tea hed Eu pe or the Ame i and l ing tree ph are onfi d t the t n As the E st nd es a d th Ph l pp ne

Prim t fi t ppe i the f l rd n th P leoce e d b ut 34 g ne a of l m s e k wn fr m the P l nd E en f N th A m a nd E pe All bel ng n the famil s Plesi ap dae and Adap dae wh h di ppe f m th re d bef the e d f the E e The best k wn f th rly l m s N tha ctus an ni mal ab t th s of a at f wh ch s e al c m ple kelet x t N tha t s was ry s mil r t th prim t xisti g lem r f Mad g r Lem d app ed f m tl e No th r H mi ph e t d the d f the E b t ar b d tly r p ese ed in th l ng f u a f Mad g s ar

A so ted w th th rly lem r w d primat tock, the An pt m ph da gr up of ts id tha derw t n e tr rdin ry d pt e d t n du the P l e e nd Eo e e The l rr the l g t of th East I d es d Ph l pp

Th l n d gal now liv g i th ea t rn A d Afr are p tic lly known fos l and the h t ry b u e All r h ghly p l ed n tu nal m l well off the m h of prim t I t n

Fossil record of higher primates F ils f the h ghe pr m t t em ly r re p rt ul ly t m th Eoc e a d Ol go wh n th e n mals were pre umably undergoing tl e r m jor radiat n Con equently relation hip am ng the higher pri mate m t l e larg ly inferred from tl e anat my and d trilution of xi ting f rm It i certain tl at the ance try of the South Am i an primat l a been di tinct from that of th Old World pr mate at l t ince th early F l ut the a e t r of n ither g p are k wn The li ing f rm are di ided int thre uperfamil e the Ceb idea Ce c p the idea a d H min d

The Ceboides (New W rld m nkey) are di tingui hed l y ha i g tl ree pr molar in tead of tw a in the ther tw gr p Two di t nct fami l e are rep esent d the Callitrichidae (quirrel m nkey) with claw haped nails a d a non p p ble tl ml and the Cel d with fl t nail and an pp al le thuml

Tl e Cer op th e idea (Old W rld m key) in lude the bal oo gue n a d lang of A ia d Afr a

The H minoidea (ape a d man) form natu r l gr p united b a m ltit de f mmon fe tures The g e t ape (g r ll r g itan and ch mpan ee) a e l usly rel ct f rm on the way t t nction Tl e gibbon mall and m re widely di tributed a e t ll flo ri hing See EUTHERIA PRIMATES (FO IL) ZOOGEOGRAPHY [D D D]

Primates (fossil)

The rd P m te ually incl de th tupa d lem rids l i es galag tar d monkey ape and m The tupa d ar ometime placed with th men typhlan ect ra In e luti n t wa d the h gh r p mat natu al elect te de l to fa tho w th large l ra n l etter ight d mo e dexter fr t feet th t f ctio d a h nds The cisor are r du ed to tw n ea h of th j w i the m key d ap S PRIMATES

S ll pro mia primate w e c mm n in the middle lat t de f N th Ameri and Europe from th Pal ene u t l th middle E ce e Ap pa ntly fau l i t r ha ge b twe th two re g on w g eatly ed ed ea d d ri g the m ddle E e Then ar d ty cre ed in th l te E d early Ol g cen th d t ib itio f the p mat hift d o thw rd n b th hem ph S me f the pro i n wer e t mel lo to p im t a to k f othe ord s uch a the In t o and the De m pte a E e in th g up th t w ely pr mat of a d al af fi t e a b ur d by the pr sen of b th l m d d t si d ch a t rs

P mat b th R ce t and m ddl nd lat Ce o e the ult of t i d fl at d ol t o n l ttl nk own p pul t o th t t nd d t f m ld r l m t n lowe lat tude

Tr lemur are c nfined t M dag ar wher they r n l te Ple t c d po t nd s li g a mal Th o ly f il of l i on t th f m th Pl ene of I d S me llent gal g f s l h e been fou d n M ce e fa a i Kenya tern Af It h b ugg ted that these n e tral t the li i g gal go Alth ugh

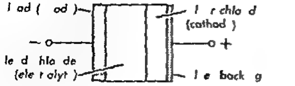


Fig. 1 Solid-electrolyte cell with solid crystalline salt electrolyte

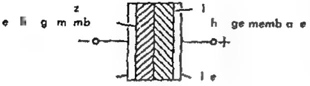


Fig. 2 Ion exchange bimetallic cell with solid electrolyte

vapor which can cause cell failure, and being difficult to make free from leakage. For examples of cells with aqueous electrolytes see DRY CELL; MERCURY BATTERY; WET CELL.

Solid electrolyte batteries. These use electrolytes of solid crystalline salts which have predominantly ionic conductivity. The conductivity is small compared with aqueous electrolytes and the current output is of the order of 10 amp/in.

Solid electrolyte batteries may be classified in two broad categories: (1) cells with solid crystalline salt, such as silver iodide, as the electrolyte; (2) cells with ion exchange membrane as the electrolyte. In either category the conductivity must be nearly 100% ionic. Any electronic conductivity causes a continuous discharge of the cell and will limit the stand or shelf life.

A typical cell with solid crystalline salt electrolyte is the lead–lead chloride–silver chloride cell in Fig. 1. Here lead is the anode, lead chloride is the electrolyte, and silver chloride is the cathode. This cell has a potential of 0.49 volt. During discharge, lead is oxidized to lead ion and silver chloride is reduced to silver.

Cells with solid salt electrolyte have been developed into miniature batteries. One type delivers 90–100 volts at 10 amp and has a capacity of 1 amp sec. This is over 10 days at 10⁻ amp. The practical life of the cell is much less but may be as much as 10 years at room temperature. It can be stored at 160 F for at least 30 days and will operate over the range −65 to +165 F. The battery is in. in diameter, 1 in. in length.

An example of a cell with ion exchange membrane as electrolyte is the zinc–zinc ion exchange membrane–silver ion exchange membrane–silver cell shown in Fig. 2. Physically, the metal electrodes are in contact with the solid membrane which contains two regions. The region adjacent to the zinc is in the zinc ion state. The region adjacent to the silver is in the silver ion state. The discharge reaction increases the zinc ion quantity and decreases the silver ion quantity in proportion to the amount of charge transferred. This cell has a potential of about 1.5 volt.

The zinc-silver cell described has serious shortcomings. The stand life is poor, indicating internal self discharge, and the capacity is limited by the available supply of silver ion. In strongly ionized types of ion exchange material the volume density of ionizing sites is about 1 equiv/liter or 0.4 amp hr/in. This is very low compared with metal oxide cathode.

A cell with higher capacity can be made by replacing the silver ion exchange material and silver by manganese dioxide plated on an inert metal such as tantalum. This gives a capacity of about 100 times as much for equal volume.

Ion exchange electrolytes are also used with hydrogen and oxygen gas electrodes. The electrodes consist of platinized metal screens. The electrolyte is a hydrogen ion exchange material. The room temperature emf of this cell is 0.96 volt. See ION PERMEABLE MEMBRANE.

Waxy electrolyte batteries. These use waxy materials such as polyethylene glycol in which a small amount of a salt is dissolved in the molten wax. At room temperatures these materials are solid. The conductivity is small and the current output is limited to about 10 amp/in.

Figure 4 shows a battery stack of cells using a waxy electrolyte. The electrodes are sheet zinc and manganese dioxide. The electrolyte is made of polyethylene glycol in which is dissolved a small amount of zinc chloride. This electrolyte is melted and painted on a paper sheet to form the separator in Fig. 4.

A 25-cell stack built as shown in Fig. 4 and measuring 0.34 in. in length and 0.25 in. in diameter weighed 1.5 g. A 0.50 in. diameter stack weighed 6.0 g. The initial open circuit voltage was 37.5 volts (1.5 volts per cell).

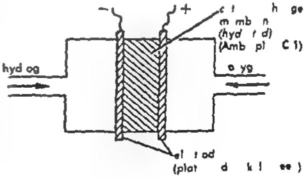


Fig. 3 Solid-electrolyte cell with ion exchange membrane as electrolyte

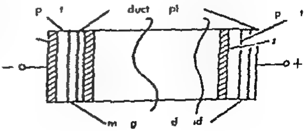


Fig. 4 Waxy-electrolyte battery stack

Table 1 Dimension l a d perform e crit ■ of som selected fl id displa me t type prime movers

Type	Size hp	Rpm	Stroke n	Bore st ke rat	I ston speed ft/m n	Br ke m p ps	D gram f c- t r or engi ■ fficiency
Steam engi	00	100 300	6– ‡	0 8 1	100–600	50 100	0 6 0 8
A tomot le engin	10–300	000–4000	3 5	0 9 1 1	1000 000	50–100	0 ‡ 0 6†
Aircraft engine	100–3000	00–3 00	‡ 7	0 8 1 1	1 00–3000	100 30	0 ‡ 0 6†
Diesel, low-speed	100– 000	100–300	10– ‡	0 8 1 0	500 1000	10 80	■ ‡–0 †
Diesel, high-speed	5 1000	1 00– 000	3–6	0 8 1 0	800–1500	50 100	0 ‡ 0 6†

Loga thmic t dard
† Air-ca d standard

T ble 2. D mension l a d perform ce crite ia f om lected fl id acc le ation type p ime movers

Type	Rat ng kw	N mber of stages	H d ft o p es- ps	T mpe atu F	Exl t p es t in Hg bs	Rpm	T p peed ft/sec	Eff c ncy
Pelton water h l	1000–50 000	1	00–5000 ft	Ami	tm	100 1 00	100 0	0 7 0 85
F ncis hydraul t b	1000–100 000	1	50–1000 ft	A bi nt	tm	360	0 00	0 8 0 9
Propeller (a d Kapl) hy draulic turb	000–100 000	1	0–100 ft	Amb nt	tm	180	0 1 0	0 8–0 9
Small nd nsing steam tu b	100–5000	1 1	100–400 ps	400 00	1 5	1800 10 000	00–800	0 5–0 8
Large cond ns- ing steam tur ne	100 000– 00 000	0–50	1400–5000 ■	900 1 00	1 3	1800–3600	500 1 00	0 8–0 9
Ga t bine	500–10 000	10–20	0 100 psi	1 00–1400	atm	3600–10 000	00 1500	0 8–0 9

Draft tube gi es g ti pres u on d sch ge de f run

on th pp ite des f the p ston ■ ts equi a lent, the t r lat e m t n of the mach ne part ( ) f e co t n s flow th gh a n zzle whe e fl d l at on i a jet (a d e) mech ni m gi es l u e m t t the ma hi e p rts by im p lse, r t on or both.

Displacement prime mover Powe uip t of a fl d displ cem t p m m ve is conv niently d term ned by p e u l me m eme t co ded n a nd c t d (F g 2) The rea f the ind cat r ca d d ded by it le gth the m n efcti p e u e (m p) i psi a d h power of th prime m e is gi en by

$$h \text{ rs po er} = \frac{m\ p \times Lan}{33\,000} \quad (1)$$

wher L t ke n f et a p st n a ea i qu in h es a d umb of cycl s c mpleted pe min t A r l m p is small th n the th o et c l m p and) ted t the the ■ l lu by d a gram f t ■ g e ffi en y (T bl 1)

Acceleration prime mover Pe f ma ce of fl id a el tr (hyd a l) p m mo rs s gi en b th equ ti n

$$h \text{ sepow} = \frac{QH}{8\,8} \times \text{effic cy} \quad (2)$$

wh e Q is water flow te in ubic fe t per sec d a d H is h ad in feet Fo heat pow r p ime m er of the fluid cceler t n typ ctu l prop e t es f the therm dynami fl id a ■ en n t ble and g aphs espec ally the M llie chart per mit th pid al tion f th w rk o power out p t f om the gen al e e gy eq at ■ which re sol e t the fo m

$$\Delta W \text{ Bt /lb f fluid} = h_{\ \iota} - h \quad (3)$$

wher h is the e thalpy in Btu/lb and the let and exhau t c d t ons c n be c ne ted by n ent pic pans for de l c d ti n mod fied f r i evers bil ty to a le e d ff ence by en g e ffic ncy (F g 3 T ble 2) Fl id c ump t follow from

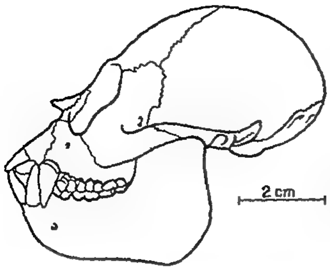
$$\text{fl d c n umpt n lb per hph} = 2545/\Delta W \quad (4)$$

o

$$\text{lb pe kwh} = 3413/\Delta W \quad (5)$$

In th fl d a cel at n typ f p ime m e jet el it e e perien ed n th ozzl c n l f nd in f et p r c nd f r n n xpan e fl d by

$$\text{j t elo ty} = C\sqrt{gH} = 8\,0\ C\sqrt{H} \quad (6)$$



Skull of *Cebupithecia sarmientoi*, a late Miocene New World monkey from Colombia, South America. (*After R. A. Stirton, 1951*)

there are numerous Eocene prosimians with tarsioid characters, there are no middle or late Tertiary forms linking them with the living tarsier.

New World monkeys (Cebidae) appeared for the first time in the late Oligocene and early Miocene of Argentina. They were already typical cebids at that time. Thus no clue is provided concerning their ancestral relationships. Others have been found in the late Miocene of Colombia. *Homunculus* is related to the howler monkey, *Neosaimiri* to the squirrel monkeys, and *Cebupithecia* to the sakis and uakaris monkeys. An aberrant extinct genus, *Xenothrix*, has been discovered in a kitchen midden in Jamaica. It seems likely that the Cebidae arose from an early prosimian group from North America.

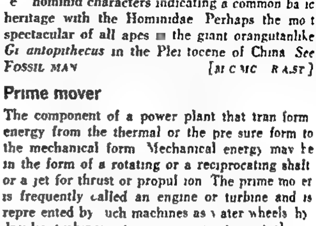
Old World monkeys (Cercopithecidae) and apes (Pongidae) seem to have descended from different groups of Eocene prosimians. The earliest cercopithecoid, *Moeripithecus*, occurs in the early Oligocene of Egypt. Other more advanced genera such as *Ankarapithecus*, *Mesopithecus*, and *Dolichopithecus* have been found in Pliocene faunas mostly in central and southern Europe. Some of the living genera also extend back into the Pliocene. Baboons, recognized at a glance because of their elongated faces, first appeared in the Pliocene and are one of the most common cercopithecoid groups. One Pleistocene genus, *Dinopithecus*, rivaled *Megaladapis* (Lemuridae) and *Gigantopithecus* (Pongidae) as one of the largest primates.

Among the most interesting primates of the Old World is *Oreopithecus* from Mount Bamboli, Italy. Some of its characters have been emphasized in support of possible hominid relationship, but allocation to the Hominoidea has not yet been firmly established.

There are many divergent lineages of apes and apelike creatures, all restricted to the Eastern Hemisphere. *Parapithecus*, known from a pair of lower jaws from the early Oligocene of Egypt with some prosimian characters, represents the most primitive of these groups. Other middle to late Tertiary genera such as *Propliopithecus*, *Limnopithecus*, and *Pliopithecus*, although related to the living gibbons, may have been more terrestrial in habits. The orangutans, chimpanzee, and gorillas apparently are the descendants of dryopithecine apes represented by the genera *Proconsul*, *Dryopithecus*, *Sivapithecus*, and others in Miocene and Pliocene faunas. The late Tertiary genera also possess hominid characters indicating a common basic heritage with the Hominidae. Perhaps the most spectacular of all apes is the giant orangutanlike *Gigantopithecus* in the Pleistocene of China. See FOSSIL MAN. [M C MC R A ST]

Prime mover

The component of a power plant that transforms energy from the thermal or the pressure form to the mechanical form. Mechanical energy may be in the form of a rotating or a reciprocating shaft or a jet for thrust or propulsion. The prime mover is frequently called an engine or turbine and is represented by such machines as water wheels, hydraulic turbines, steam engines, steam turbines, windmills, gas turbines, internal combustion engines, and jet engines. These prime movers operate by either of two principles (Fig. 1): (1) balanced expansion, positive displacement, intermittent flow of a working fluid into and out of a piston and cylinder mechanism so that by pressure difference



(a) (b)

Fig. 1. Representative prime movers. (a) Single-acting, four-cycle, automotive-type internal combustion engine. (b) Single-stage, impulse-type steam turbine.

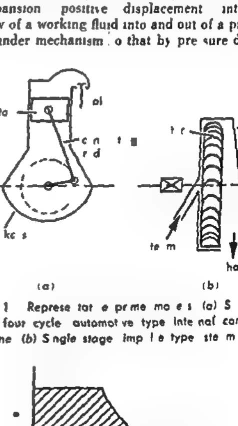


Fig. 2. Pressure-volume diagram (indicator card) of fluid-displacement type of prime mover.

Prim rs f r galva i ed irc n ually c tain sub- s u l quant t es of metallic m c bec ther types d n t m g ne al dhe well t gal a ized m especiall on e te r e posu e Th e p im s y also be u ed on ther metal in whicl ca e th es fi al to f the zinc prot cts tl e un d lying metal

P im for po s m terials mu t eal tl e r face dequ t ly t pro d a u f rm ba for f i ture co t g Bec e many f tl e e m ter al are ' kal n e t n high lkali m stance is an other important eq m nt Such m ter al re hen called e l rs Porous s rface often aid in adh th u b mech cal nterl king that extrem adhe i n, chem ally n ot always r q ed Beca m ny f the e po urf a e gh ma prime s also de ig ed to f ll th urf ce d pro de a moothe su f for f ture p ts.

Whe the s rf e to be painted is att ked by he sol ents in the top ts p mer whi h will l th u d lying s face and i late it fr m at tack mu t be u ed Th i a c mm n p blem i pa ng ov a phalt other b t minous m te i als. I th s as a w t r lc hol thinned pr mer u d ted I ther es the p m mu t be h sen f th p rt cul pr blem

P m rs re al ay p gmented I cl ar f n he th coat h h pe f rm th s f ncti n de bed as a seale an u der t r a wa h coat *See* Co so *tov* PAINT SURFACE COATING

[F S D]

Primitive gut

Th tub l tru tur embry wh ch d ff en tiates into the l m nt ry ca al The method by h h the p m t e g t a ise depend ch efly o th y lk o te t of the g

Two-layered blastoderms Eggs w th sm ll od te m nts of yolk us lly d l p nt heric l bl t l e wh ch i agi ate t the g t tive pri l t f rm d ubl w lled ga trul e The in aginated ac exte d le gth to become the primitive gut. I om gro p s h s the h no- derms, h et gnath chord t a d mph b n its ext rnal pening the bl t p e p r t th anus. The m th f rm s a new pe g by contact of th pp te e d of th g t w th the k n h ch th n p f ate In the gr up like th an l ds, rthrop d nd m ll sk the bl to- po bec m th mo th a d w a l g ng s f rmed

Three layered blastoderms A m l with m yolk th n c b le d s fi h ept l d b d f m fi tt ed g trulae c n t g f th l y ered bl tod rm surm nt g the y lk M mmal a so bel ng th s g oup lth gh th y lk has been l t sec d rily in all e pt the mon t m The h ad i f rmed by a fold g of the bl st de m pon it If The e t d rm l laye w th th h d f ld bec m th ph rynx Th f regut e t d d h an nt ri g th f th wh l h d d by the union f l t l t derm l f ld t it p ter

boundary In m t f rm the h ndg t arises by a similar f lding i the oppo ite d recti n the tail f ld at the p teri r end of the l lastoderm The shark is an ex eption in which the hi dgut f rmed by the un n of two lat ral ent dermal ridges l e eath the n tochord much a the med l lary plat folds int neur l t be ab the n to- ch rd The midgut remains pen unt l the entoder mal layer of the bl toderm urro d the yolk The comm icati n of the m lgut w th the yolk gradually narrow t an umb l cus as tl e foreg t hindgut d late al body f ld pre s in from all de but the midg t flo r i brought i to position only with the ab rption f the y lk sac Mouth and a u form by contact f the ph rynx and hind gut with the t derm t their re pective ends of the b dy h hem o l incomp t b l ties f ecto- derm and entode m au e uch areas f c tact t p rforat a d fo m the body o fices

Teleo t fi h re an ption to the bo e ac co t in th t th true ent derm doe t pread be- th the whole bl t derm b t is confined to the embryo are Al ng the x s of the body be- ne th the n t h rd th e toderm d es i to a s l d r d which th hollows ut econdarily t f rm th primit gut. *Se* CLEAVAGE EMBRYONIC DEUTEROSTO IIA GASTRULATION OVUM PROTERO- STOMIA [H L H]

Primulales

A mall ord r f the pl t ub lass Dicotyledoneae conta n g 3 f mil e with 70 ge d 2100 spe c e These r of n omic importance except as orn ment l Two cl aract t c f tu es are the opposite tamens d the free e tral place t Th fiv stam are opp t th f pet l nstead f be ng alternat w th them becau e the uter i l f st me is ab rti and represented by mere rud me ts c ll d stami d The f th flowe projects i to the ry ca ty as a central sh ft t which the ovules ttached a cond t n desig t d free c tral pl ce t t n H bel ng uch fam li orn m ntals as d pl mbag cycl me d th prim ose *S e* DICOTYLEDONEAE EMBRYOPHYTA PLANT KINGDOM [P D S]

Printed circuit

A gen r c te m appl ed to a meth d f fab cat g elect ire t g of d ctors d el c tro omp nt (t n e i d t ces and c p t ces) by ny f al gr ph c rt pro ess nted t m k econ m al m p o- d ct n pos ble e p and w ght nd n e li b l ty f le t eq pme t They e d inp t lly ll typ s of l t o eq p- ment ch ad nd TV ets l ct i l w g beh nd th d shb d tom b les gu ded mi ll d born le tr n c equ pm nt m p ter a d dust l co tr l q pm nt

The p d dopt f th g ph t p c es by th lect m d try dem t t o of th eff t e e s of th p oce s i a h e cost d ct n d eq pm t m m tur ti n

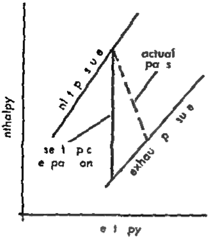


Fig 3 Enthalpy-entropy (Mollier) chart showing performance of steam or gas turbine type of prime mover

and for expansive fluids by

$$\text{jet velocity} = C\sqrt{2g\Delta W} = 223.7\, C\sqrt{\Delta W} \quad (7)$$

where H and ΔW are as given above and C is the velocity coefficient seldom less than 0.95 and usually from 0.98 to 0.99

Selected representative performance values of some prime movers are presented in Tables 1 and 2 For further details *see* INTERNAL COMBUSTION ENGINE STEAM ENGINE TURBINE [T B]

Bibliography A H Gibson *Hydraulics and Its Applications* 4th ed 1930 L C Lichty *Internal Combustion Engines* 1951 T Baumeister (ed) *Marks Mechanical Engineers Handbook* 6th ed 1958 J K Salisbury *Steam Turbines and Their Cycles* 1950 E T Vincent *The Theory and Design of Gas Turbines and Jet Engines* 1950

Primer (explosive)

An agent used with explosive propellants and pyrotechnics to produce the initial fire The primer itself may be initiated by percussion stab action friction or heat The gases and hot particles from the primer serve in turn to ignite a larger mass of material for example the gunpowder in a cartridge the primary explosive in a detonator cap or the powder train in a fuze The term primer is sometimes loosely applied to a detonator

The amount of primer used is usually about 0.1 gram or less A common example is the tiny globule that may be seen on the ends of the fuse wire post in a photographic flashbulb this material serves to ignite the aluminum foil

Although primer compositions deflagrate rapidly they do not detonate In fact a detonating action would be most undesirable because it would tend to blow away rather than to ignite the charge The total burning time of a primer is about 500 microsecond

Primer mixtures sensitive primarily to friction may consist simply of potassium chlorate as the oxidizer and antimony sulfide as the fuel Such a mixture produces hot particles as well as gases Ground glass or silicon carbide may be added to increase the frictional effect and sulfur to make the mixture quicker (more sensitive) Also very fine grained black powder (meal powder) is sometimes added The ingredients are made up in a paste with a small amount of gum arabic which binds them together when the paste dries

Cartridge percussion caps usually contain a primary explosive such as mercury fulminate in addition to the materials mentioned above However primary explosives are not essential they may be replaced by other materials such as lead thiocyanate Lead compounds seem to be preferred probably because of the hot particles of lead oxide that they produce Lead styphnate (2 4 6 trinitroresorcinate) is now a common percussion cap component

In detonator caps the primer is often of a match head composition In fact the formulation of primers is quite similar to that of matches and pyrotechnics and ingredients such as potassium chlorate sulfur and antimony sulfide are common in all applications *See* DETONATOR EXPLOSION AND EXPLOSIVE MATCH PYROTECHNICS [W E C]

Bibliography T L Davis *Chemistry of Powder and Explosives* 1943

Primer (surface coating)

A material used for the first coat of paint Primers are designed to promote adhesion of the coating system to the substrate to furnish a good base for further coating and to prevent attack on the substrate by air water or other material Primers are not intended to contribute exterior durability or appearance

Primers for wood are formulated to give the maximum adhesion to the wood and to provide sufficient flexibility to adjust to the dimensional changes which occur when the wood swells and shrinks because of changes in moisture content When designed for exterior wood they should also be resistant to the penetration of moisture and to the action of moisture in destroying adhesion Primers for interior wood often called undercoaters must also have good adhesion to wood and because they are often used under enamel must give a smooth film and permit easy sanding

Primers for metal must in addition to giving good adhesion prevent the spread of rust from scratches or other damage which uncover the surface For this purpose they usually contain a corrosion inhibiting pigment which retards the electrochemical reaction that causes corrosion The most common inhibitive pigments are red lead zinc chromate and basic lead chromate A number of other related pigments are often used and numerous others have been suggested Because all these are somewhat toxic primers based on red iron oxide are often used when they are to be dry sanded or when for other reasons toxic material must be avoided These pigments do not have any inhibitive action but rely on a tight film to prevent corrosion

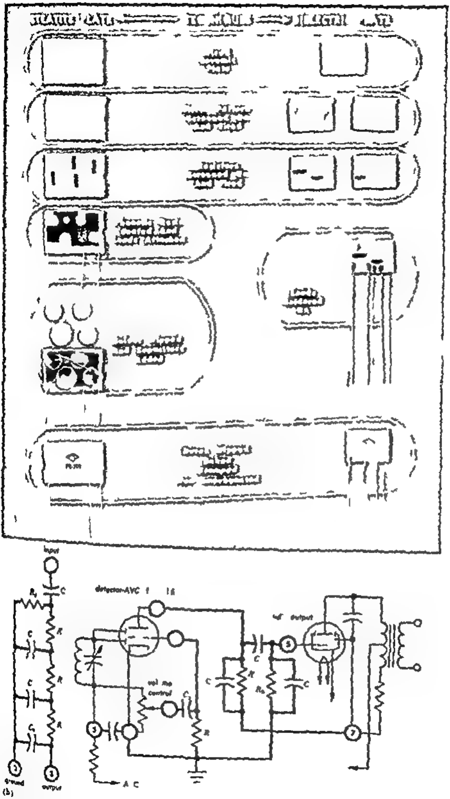


Fig. 2. P [illegible] d [illegible]
Circuits [illegible] m b e m t [illegible] s th d elect [illegible] th c p [illegible] m d by sc [illegible] g [illegible] ed [illegible] d [illegible] ppo [illegible] d [illegible] th pl [illegible] dered to base. C [illegible] me c p to [illegible] (b) S h m t d g m of [illegible] (C [illegible] b [illegible] d o [illegible] D Gl b [illegible] m c. Th b pl t [illegible] d

Printed circuits are of interest to industry for the following reasons:

1. Printed circuits are the common denominator for almost all approaches to the mechanized fabrication of electronic equipment.

2. Use of printed circuits has greatly reduced the labor required for the wiring of an electronic circuit. This is specifically true for small electronic units used in airborne or guided missile equipment.

3. Printed circuits can be manufactured more uniformly because the graphic art processes are mechanized.

4. Uniformity of printed circuits improves the quality of the product through simplification of quality control.

5. Printed circuitry has helped to minimize one major cause of unreliability in electronic equipment by permitting the use of dip-soldering processes. (In dip soldering the joints between the electronic component and the conductor are exposed to molten solder and joined in one precisely controlled operation.)

The most commonly used printed circuit processes may be divided roughly into three main groups listed in the order of greatest acceptance: (1) material removal processes, (2) film deposition processes, and (3) mold and die processes.

Material removal processes. Of the material removal processes, photoetching and stencil etching are probably the most widely used techniques. These are used primarily in the fabrication of printed wiring.

Photoetching. In photoetching the etchant resist pattern (conductor pattern) is formed photographically and is capable of providing fine definition of the conductor lines such as those required for small commutators and switch contacts. A photosensitive film is applied to a copper foil which is bonded to a plastic laminate such as paper-base phenolic. A photographic negative of the circuit pattern (originally drawn several times full size) is superimposed on the sensitized film, and the film is exposed to ultraviolet light. This method is similar to the production of a photographic positive. After exposure the photosensitive film hardens. The plate is then placed in alcohol, which dissolves the unexposed film from the copper foil. The exposed areas are left covered by the hardened film, which serves to protect the copper foil during the subsequent etching process. The uncovered copper is next dissolved in an acid or ferric chloride etchant bath. Finally the hardened film is dissolved from the exposed areas, leaving copper conductors in the original circuit pattern (see Fig. 1).

Stencil etching. In stencil etching the protective film forming the circuit pattern is applied by a printing process such as silk screening. The protective film, usually an enamel, is dried, and the exposed copper is etched as previously described.

Film deposition processes. The mechanical application technique, stencil screening, and electroplating are the deposition processes most often used for the fabrication of circuits on either plastic or ceramic base materials. For components such as precision resistors, vacuum deposition techniques are used, usually on ceramic or glass base material. Chemical or photochemical reduction techniques

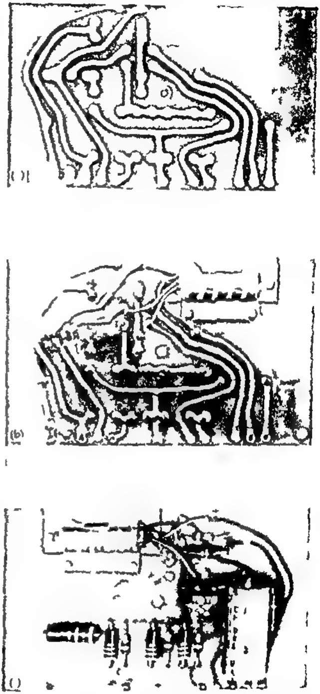


Fig. 1. Etched copper circuit on epoxy-glass laminate. (a) Copper circuit pattern with etchant resist removed is ready for drilling of holes to mount component parts. (b) Circuit pattern side of board with component parts mounted and lead connections soldered. Subminiature tube was mounted and tube connections made after the [illegible] of the parts were dip-soldered. (c) Component side of board shows parts mounted through holes in circuit board. After the parts are soldered, a coating of epoxy resin is applied on both sides of the circuit board to serve as a moisture barrier and to bond the parts to the board. (Ramo-Wooldridge Corp.)

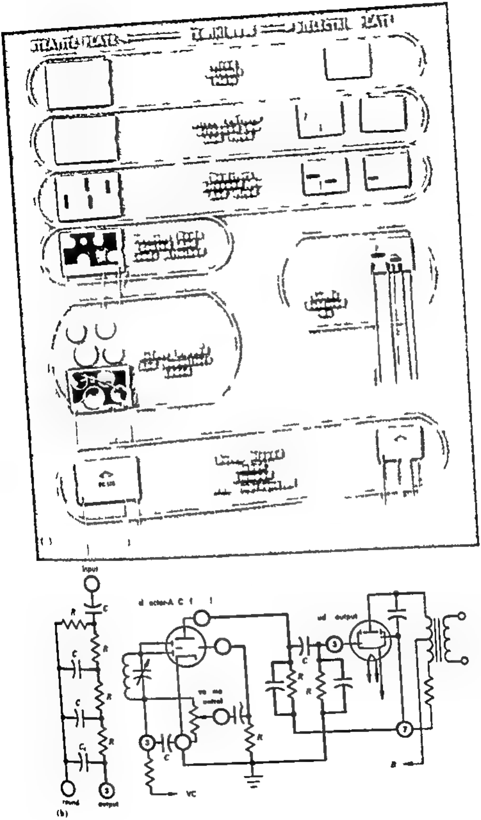


Fig 2 P i t d i it mi b m t l l th di l t l F th p it f m d by l g
) Cir ts l l f c l m d t tt d ti o pp it id f th pl t
cera th b m t t t mic p cit l (b) S h mati d g m of i c it in ( ) (C t / b
d red to b Cl t ight l m d Gl b U / f)
high d t t ic t t mi Th b pl t l d

Printed circuits are of interest to industry for the following reasons

1 Printed circuits are the common denominator for almost all approaches to the mechanized fabrication of electronic equipment

2 Use of printed circuits has greatly reduced the labor required for the wiring of an electronic circuit This is specifically true for small electronic units used in airborne or guided missile equipment.

3 Printed circuits can be manufactured more uniformly because the graphic art processes are *mechanized*

4 Uniformity of printed circuit improves the quality of the product through simplification of quality control

5 Printed circuitry has helped to minimize one major cause of unreliability in electronic equipment by permitting the use of dip soldering processes (In dip soldering the joints between the electronic component and the conductor are exposed to molten solder and joined in one precisely controlled operation)

The most commonly used printed circuit processes may be divided roughly into three main *groups listed in the order of greatest acceptance* (1) material removal processes (2) film deposition processes and (3) mold and die processes

Material removal processes Of the material removal processes photoetching and stencil etching are probably the most widely used techniques These are used primarily in the fabrication of printed wiring

Photoetching In photoetching the etchant resist pattern (conductor pattern) is formed photographically and is capable of providing fine definition of the conductor lines such as those required for small commutators and switch contacts *A photosensitive film is applied to a copper foil* which is bonded to a plastic laminate such as paper base phenolic A photographic negative of the circuit pattern (originally drawn several times full size) is superimposed on the sensitized film and the film is exposed to ultraviolet light This method is similar to the production of a photographic positive After exposure the photosensitive film hardens The plate is then placed in alcohol which dissolves the unexposed film from the copper foil *The exposed areas are left covered by the hardened* film which serves to protect the copper foil during the subsequent etching process The uncovered copper is next dissolved in an acid or ferric chloride etchant bath Finally the hardened film is dissolved from the exposed areas leaving copper conductors in the original circuit pattern (see Fig 1)

Stencil etching In stencil etching the protective film forming the circuit pattern is applied by a printing process such as silk screening The protective *film* usually an enamel is dried and the exposed copper is etched as previously described

Film deposition processes The mechanical application technique stencil screening and electroplating are the deposition processes most often used for the fabrication of circuits on either plastic *or ceramic base material* For components such as precision resistors vacuum deposition techniques are used usually on ceramic or glass base material Chemical or photochemical reduction techniques

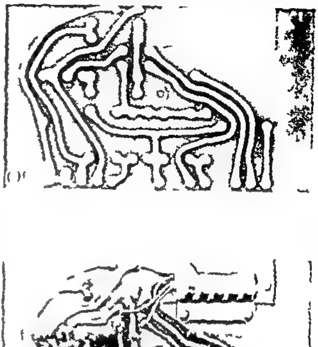
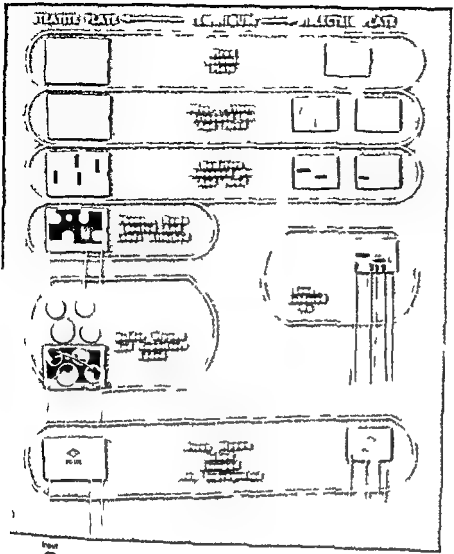
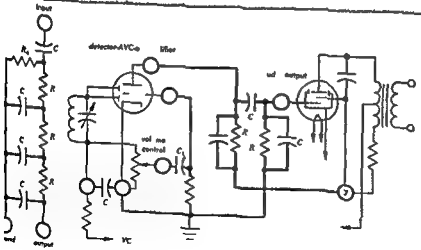


Fig 1 Etched coppe cu t on epoxy-glass lami ate *(a) Copper ci cu t patte n w th etcha t re i t emo ed is eady fo d ll ng of holes to mo t compone t parts (b) Circ t pattern s de of boa d w th compon t parts mounted a d lead co ect old red S bminiat e t be was mo t d a d tube con ect s made alte the est of the rts we d p-solde ed (c) Compo e t s de of boa d hows part mov t d th o gh hol s in circu t boa d Afte the part a e sold ed a coat g of epo y r In l appl ed o both sid of th c c it boa d t s rve a a mo tu ba e a d to bo d the parts to th boa d (Ramo-Woold idge C p)*





d t
l ft c l m m E m t l th d l ct f th p t f m d by g
m t t d m t t o d ct opp t d f th pl t
C t l m p t 1 (b) S h m t d g m f t ( ) (C t l b
t t ght f m d a D Gl b U f J
m c. Th b pl t d

are used for deposition of materials to form resistances or capacitances. Photoelectrostatic techniques have also been developed primarily for the fabrication of conductive elements.

Screening method. The screening method to form the circuit (conductors, resistors, capacitors, and in some cases low-value inductances) uses ceramic or glass as a base material (see Fig. 2). A silver paste, usually with a glass binder, is applied through a screen stencil to form the conductor pattern. The stencil is usually formed by a photographic process similar to that used for the photoetching process previously mentioned. After the silver paste has dried, it is fired in a furnace at temperatures between 750 and 1350°F to bond the silver pattern to the base.

Resistance components. Resistive elements are usually formed by one of the three methods listed in the order of degree of precision required: (1) screened or sprayed, (2) applied as a tape, and (3) vacuum deposited.

Resistive inks are composed of various forms of carbon with a resin binder (such as phenolic or epoxy) and a solvent vehicle. This mixture is applied through a stencil to form a rectangular pattern between two conductors and then baked at a temperature between 150 and 600°F. The value of resistance is determined by varying the type of carbon used, the ratio of carbon to binder mix, the aspect ratio (the ratio of length to width) of the rectangular pattern, and to some extent the thickness of the film. Resistive elements printed in this manner have wide tolerance limits, and it is usually necessary to adjust the resistive value by some means such as abrading the surface or one edge of the pattern. Thus the resistive element is formed with a value below that required and then adjusted to fall within the design tolerance limits. The stability of the resistance value is dependent primarily on the type of carbon used and the binder material. In general, resins cured at higher temperatures provide more stable resistance values. Thus an epoxy or silicone binder would provide a more stable resistance than that obtained with a phenolic binder. Printed resistors of the type mentioned above are used primarily in consumer products, such as radio or television sets, where the tolerance requirements and operating environment are not too severe.

In order to overcome the difficulty of producing resistive elements to close tolerances and to increase the probability of producing a number of resistive elements on the same circuit base to reasonable tolerances, the tape resistor was developed. This form of resistor is capable of operating at temperatures up to 400°F. The resistor is fabricated by spraying metal-free asbestos paper with an ink composed of carbon, silicone resin, and solvent. The tape is applied to the circuit base and is then cured at 575°F for several hours to polymerize the resin. Curing of the resin binder also bonds the tape to the circuit base, thus forming the completed resistor. Resistance values between 10 ohms and 10 megohms ±6% within an area of 0.13 by 0.30 in. are obtainable by changing the type of carbon used and the ratio of carbon to resin.

Fabrication of printed resistors by vacuum deposition is an expensive process, and there has been no general application of this technique except for precision resistive elements. Usually alloys with a low thermal coefficient of resistivity (such as nickel-chromium alloys) are deposited as a thin film on a glass or ceramic base by vacuum evaporation techniques.

Capacitance components. Printed capacitors are fabricated as part of the conductor circuit pattern when a high-dielectric-constant ceramic, such as one of the titanates, is used as the circuit base material. Conductive patterns are screened on opposite sides of the circuit base to form the capacitor. The dielectric constant of the titanates varies widely with temperature; thus these capacitors are quite temperature-sensitive and are limited to circuits that accommodate wide circuit tolerances.

Most printed-circuit capacitors are disks fabricated from barium titanate with additives to obtain temperature stability. These ceramic disks are silvered on both sides in much the same manner as the circuit patterns were formed on a ceramic base. The capacitor is joined to the ceramic circuit base by the use of lead-tin solder containing approximately 3–5% silver to prevent the molten solder from dissolving the silvered conductor.

Plating process. In the plating process (second only to etching in popularity for the fabrication of circuit conductors) a plastic laminate, such as paper-base phenolic, is first coated with a material that conducts electricity. This may be done by forming a 0.0001-in. silver coating on the surface of the laminate in much the same way that mirrors are silvered. The silver film is then coated with a

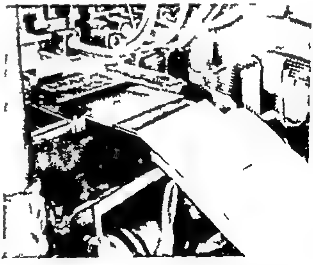


Fig. 3. Close-up of machine embossing a copper foil circuit pattern onto a phenolic paper laminate. The copper foil feeding into the machine from left to right has a temperature-resistive adhesive on the underside surface. During the embossing operation a hot die cuts the circuit pattern, embeds the edges of the conductors into the phenolic, and temperature cures the adhesive to form a bond with the base plate. (A. W. F[illegible])

pl t g resi t, u ually an enamel by a ste l ng process, I g e p d areas t f m the cuit p ttern Th plating pr is sim l r to the plat g of dec t e metal After suffi nt thi k ess (u ally 0 001–0 005 in) of copper i depo t d th pl t g esist i rem ed by a l e t The x posed sil film is rem ed by cid et hing I g th m h th cker pper plating t form the cu t pattern n the pla t c she t For electron c cu ts th t may be s bject d to hi h hum d ty d to un s pplicat on f oltages (h th t con dti f l e mig ti exist) the chem c l re d ct n f c pper n t d of sil er s u ed t f m the pl t le t od All the ub q ent p o es re s des bed p e i sly

Mold and die processes Of the m ld a d die p ocesse mb s ing nd tampi g a e the mo t pop la (e F 3) In gene l th e two p oc esses a e ed f r th fab catio of nd tor r d ct n e U u lly c pp f l mb s ed on a ph ol l minate ba e plate o p wde ed l er tamped pla ti sh et Be u e of the r la tr l h gh t f tool g d c t f br ti n l m tat s these pr ce ses h e n t gai ed wid ge [L K L]

B bl g phy C. Bru tt (ed) *A o Adt in P t d C e t* N tl B r St d ds M P bl. 19 1948 F M H m L K Lee E R Gamso d R F N wt n *D t l pm nt a d Ap pl t f Automati As embly T ch q es f W tu d El t c Eq pm t* Wright Ai De l pme t C te T h Rept 55–230 1955 *P o d g of th Symp sium n P i ted C* u R d El ctr n c T le s n M ufa t s A soc 1955

Printing

F the West n Wo ld p t g h d t beg n g d r ng th fi th l f th filt e th c t y with th in t n of p t g f m mo bl met l typ Th in t i mm ly a c d t d t Joh G tenb g h name t d y i h fly a so at d th th G t nbe g B bl p ob bly the m t fam book ev pr t d P t g fa cr d rt d f m m ble typ w pr d ed n H ll d wm bef Gut b g beg h act i h es d th D t h s be th t e Lau J n Cot f H a l m The h t al ev d nce d b ted by g r t o f s h l d es t d fi t l e r bl h any e m n a th m ent F gm ts f th rly p t ng k w u b l dle pri t g h m d d p eserved i E p nd Ame mu m B th G t be nd Co t r w p c d d by es l t by a Ch ne e P Sh ng wh pri ted f m m bl t pes mad f e rth nw bef e th y A D 1100 h e Ch e f the rt th n d b qu ntly h d pe pt bl imp rt Eu pe

R g dl f wh the i nt r m y h be the m n n t ly w the t rt g p t fo h t od a m lt h ll d ll d t y b t w f th most ign fi t e t n h m n h story It was gnifica t even re oluti nary in tw respe With mo abl types a cast by Guten berg (small rectangular p eces of metal of uniform h ght a d b dy thickne s with a letter or other ch acter in rel ef on ne end) it became po sible f r the fi st time t as emble lette s into words w d int l ne and lines into p ges and to nk and print the pages Thereafter when wiped lean of i k the page li es and words could be di a embled and the types ret rned to their respec t e c mpa tme s th type case ready to be us d again in anothe job Up to that time tl e we ter world had known only block p inti g—the cutt g of cr d p ture and lette ng o a block r bl cks f w d The p ts that wer n t to print were cut away as to le e the li s of the pict e a d the letter g i rel f S ch l ttering cut for specific wordag was an i tegral part f the bl ck and ould not be d as mbl d and i mp ed

A seco d a d m important spect of the in n ti n w s that gai for th first tim i w te n hi t ry it m de dupl cat n by other tha m nual meth ds po ble Bef re the time of C te be g and C st r the te t f all bo ks as well s f mall r pie es was lett d by ha d Wh n for e mple a m na t ry de ed a w add ti n l copy of the B ble the ribe we et to wo k l bori usly c pyi g the Old a d New Test m nt nd pos ibly th Apocrypha s well n p hm o ell m w th a q ill pe b u h Lat r the w k wo be r bri ated a d metime emb ll hed with i tial ament a d e e p tu s d n g ld leaf nd e al col r All th might equi e th ollect ff rt a d t le ts of ev al s c si e g er ti s f ha d aftsmen a d in th e d the r ult wa ngle opy With the i ent o f pr t g it b me po ble to pr d e ident l c p e as ma y the p ti c a d gy f th pr t d th e tent of hi te h c l fa il ti s m ght p rm t d th i turn made t p ibl t p t m re inf rmat n t the h d of m r pe ple n l st m and t l we t nd the by t p e d l te y a d l g m w d ly a d r p dly tha had e e be p ible b f e

It w th s p cede ted ab l ty t d pl cate t pr du e m ny d t al c p e i tead f a si gle opy that ca ed pr nt g e ly day t be s at d with m gi a d k wn a th k Art

The p e ent d y p i t ng i d stry may be said t h e ea h d t e r t st t s p m r ly a th It f fo maj r de el pment f which th i t f p nt g fr m m ble type was the fi t The se nd m 400 y r l t w s the n t n f the mpo g m h n wh ch d d m cha cally nd q kly wh t Gut b g nd h s rs f ge er ti n h d d n l b r o ly by ha d Th d w the appl t n f p w r t the p i t g p e ulm att g n the de elopme t f th h gh peed web fed m lti l r r t ry p e s a d f th the ppl n t p nt g pr ce s f th m a—fi t t ph to g g th n to l thog r ph e pe ially offs t d m t r e tly i ph t typ g aphy t the c mp t on f type matt

It has often been said that the key to the future in the graphic arts is the camera, and it is possible that this last development may in the end turn out to be the most important of the four. Meanwhile, as in every mechanized industry, other technical developments, some now in the experimental stage, some already in being (for instance, printing in which ink is "jumped" from type to paper across a gap), may revolutionize the industry, not necessarily overnight but on short notice, and thereby may render obsolete some or all of the procedures and techniques described in this article.

In the printing industry of today there are three major methods or processes in use for transferring ink to paper. These are (1) relief or letterpress printing, in which the printing surface, composed of type and printing plates, is in relief and the nonprinting parts are below the printing surface; (2) planographic printing, in which type matter and pictorial material, transferred (usually by photography) to a single plate, are printed from an even surface; and (3) intaglio printing, in which the parts that are to print, both typographic and pictorial, are cut or etched into the plate and are below the plate surface.

The term letterpress is used in book publishing to refer to the text matter or typographic content of books as well as to the relief printing process.

To the above is sometimes added a fourth process, screen or stencil printing, in which ink is brushed or squeezed onto paper through a stencil that may carry either pictorial or typographic material or both. This process, however, accounts for a comparatively small percentage of the total volume of printing. There are also specialized processes of limited application, as found, for instance, in copying machines, which are considered in another article. *See* PHOTOCOPYING PROCESSES.

RELIEF PRINTING (LETTERPRESS)

Relief or letterpress printing is the oldest of the three major processes, with a history that dates back more than 500 years (twice that if its beginnings in China are included). Although other processes, notably offset, have shown a relatively greater percentage increase in volume in recent years and have taken over an increasing amount of work formerly done by letterpress, it still remains the basic process and the largest in volume of the three. It is used today for almost all newspapers, for books and magazines, and for the general run of advertising, commercial forms, and miscellaneous printing.

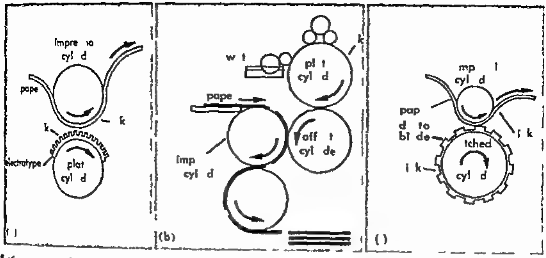
Typesetting. In the procedure usually followed in letterpress printing, copy, marked for size and face of type and for length of line, is sent to the composing room, where it is set in type, usually on one of the hot-metal composing machines—Linotype, Intertype, or Monotype, or Ludlow Typograph in the larger type sizes. Foundry-cast type for hand setting is also used but mostly for headings and the like. The resulting composition, including heads, body matter, captions, and incidental matter, after having been proofread and corrected, is then assembled into pages, along with line engravings (printing plates made from pen-and-ink drawings and other art work done in line) and halftones (plates made from photographs, wash drawings and other art work done in continuous tone). *See* COMPOSITION (TYPE); PRINTING PLATE.

In the printing of large-edition newspapers, type and plates are assembled into pages and the pages each locked up in a heavy metal frame called a chase, which holds all elements of the page securely in place. A thick sheet of papier-mâché, the stereotype matrix (mat), is then placed over the type page and squeezed down upon it by hydraulic or mechanical pressure so that, when removed and dried, it constitutes a mold or matrix of the page. From this in turn a stereotype plate is cast, usually in semicylindrical form and about ⅝ in. in thickness. The curvature corresponds to that of the printing cylinder of the press on which it is to be used. If the page or part of the page is to print in a color or colors (in addition to black), a separate mat and plate are made for each color.

Rotary presses (newspaper). Because of the high production speed required, the large metropolitan dailies are printed on web-fed rotary presses, which print from large heavy rolls of newsprint paper that pass through the press in continuous webs, and which carry the printing plates on the surface of printing cylinders. Each printing cylinder usually carries four or eight plates and thus will print four or eight pages on one side of the web at each revolution. An impression cylinder keeps the web pressed against the plates, which are inked by a set of rollers also tangent to the printing cylinder.

The large rotary press consists of a number of printing units, each containing two printing cylinders (complete with impression cylinders) and each printing on a separate web four or eight pages on one side and four or eight pages on the other. Any or all of these units may be brought into operation depending upon the number of pages to be printed and may be used for additional sections or for color printing. (The increasing use of color has been one of the outstanding developments in newspaper printing during the 1950s.) Eventually the webs from the several units are brought together and fed through a device built into or attached to the press which automatically gives them their down-the-middle fold, cuts them into individual papers with pages in consecutive order, folds the papers across the middle, and counts them—all this at speeds of 50,000 or more impressions per hour per press unit. Web speeds in the larger rotaries average about 1500 ft/min.

For dailies of smaller circulation which still must meet exacting delivery deadlines, a smaller type of rotary press is built, the tubular press—so called because the stereotype plates used are cast in cylin



P nt g p s ( ) R l f (b) Pl g ph c ( ) I t gl

dr al instead of micylindr al form nd are carried p i t g cyl d s f c p ndingly smaller diamet Th e p esse consist of up t f ur ts, e ch sually printing f p g two on ab of th web and e c pable of d li e g l r 16-p g paper at peed f a nd 45 000 ho

F dail es f only a f w thousand culation and f weekl pap th re a al typ s of m e r l s spec al ed p e s me printing from b nd som f om h t S me of th op ate on th fl t bed p i ple d r ost p int d ctly from the type p g w th ut use f ste e types or th r form of d plic t plat s

Rotary presses (magazine) Th b d t nat nally re l t d mag zin wh d e lette press (*L f Th S u day Even g Post* and *R ad r's D g t* are x mpl s) e pr ted o eb-fed ta gene ally n l in per t ng prin pl t th e ed fo the l ge d l b t with tw po nt f diffe n the pre m ke poss bl the pri t g f llu t at n i f ll colo from fine-sc halft o b th sid f th b and a diff re t fo m of dupl te plat the lectrotype (l tr) s ge erally ed i t d f the tereotyp The le t otype pr p red by mak ng m ld f the type page h lito pl te a th may b th n uspe l g this m ld n a bath (pp ulf te a d s lf ic cid wh by p ted o t, and fi lly po ing m lten type m t l nt th h ll t ba k t p a d g i th body a d stre gth r q i ed t t d up the p ss fter d pl n g t down t the r q d thi knes F lect type i te d d fo ry l g ru eventually w th col red i k (me f wh ch b m all n copper) th n urfa e of kel i lectrod po ted fi t foll wed by c pper shell and b k up m t l. Th lect otyp is m e pen e and t kes l to m ke than the t reo- t p —from 2-8 h u —b t s mo d bl a d g m re f thful fi qual ty dupl c t n of 120-

d 133-li e h lft in b th bl k and white and color s ch are us d in sl k paper maga ines in m h bo work d the bette gr des of ad ertising p i t g

Ste eotypes m y b m de the c rved or fl t el ctr types are mad flat and if fo u e n tary p es es rv d by mecha c l p e

Electrotypes and st typ ha e b th l g b used b k pr nti g particularly wh n the first ed tion is la g d b que t ed ti ns likely A m re r e t de elopment for b ok w k d ipl cate plate m d f bb r on a flexible m unt ng which can be bound ar d the p i t g yl d r f a tary pres Duplic te pl t of m ld d rub- b r pl st nd e nylon are al in use f book m ag zine nd mm l p nt

Flat bed presses Smaller ed t p nt ng when d ne l tterp es (publicat on b klet p mphl ts busin ss f m fold th al u f c m m rc al pri tin) i du d m tly on one n th r f rm of flat bed pre s called b au e the typ pag d pl te plate (if s h plates d) t d f b g l ked th urfa e f a inti g yl nd p t ed on fl t lid g b d h nt l n m t p e e wh ch mo e k d f th nd yl der M t f th t ng d t w b b t o h t f pap ng ng i s e f m 12 by to 44 by 64 i d la g Th yl d n t a p t g cyl d st d t e l t an dg of th heet t gr pper d the sheet und w th it b g ng t nt ta t w th th f m f typ page o plate as the b d l de th ugh ne th the eby p i t ng sid f th heet Fo m m y st of 4 8 12 16 mo e p g (they ge lly in mult pl of fo) wh e l cked up t g th a cha d p t d n gl mp es on A th bed f the p s i tur ed to it r g l po t on the yl d r s a d by am t on th t it will n t e m i nt t w th th f m wh l at the am tim t d l p t d h t t tap m l dev e

which carry it to the delivery end of the press and deposit it on the sheets previously printed.

Presses of this type are also known as cylinder presses and in most cases require two revolutions of the cylinder for each impression.

The sheets produced on flat-bed presses, after being printed on both sides, are folded by machine (or sometimes by hand) into signatures of 4, 8, 16, 32, or more pages, with pages in consecutive order, and the signatures subsequently trimmed to a predetermined page size. A printed piece such as a booklet or catalog may consist of one or several signatures, the latter held together by wire staples, *thread (as used in books), or wire, plastic, or other* mechanical binding.

Flat-bed presses are made in various sizes and models, including some that operate vertically. They do not have the speed of rotaries, production ranging approximately from 1500 or 2000 to 6000 impressions per hour, depending upon size of sheet and nature of work, but they are far more flexible in terms of short and long runs, different sizes of sheet, and ability to handle a wide range of work, and cost less to purchase and to operate. They are in general use in commercial printing plants and are capable of turning out a wide range of high-grade printing.

Platen presses. Small printed pieces, such as envelopes, postcards, stationery, circulars, and small business forms, are usually printed on platen presses—the familiar open-and-close or clamshell action type of press common to printing plants generally, particularly the smaller ones, and generally known as job presses. They may be either hand- or mechanically fed. Or, if required in large editions, these smaller pieces may be printed on large sheets from two, four, eight, or more identical type forms, plates, or sets of plates, the sheets being later cut up into the individual pieces. Often also such jobs may be ganged up, that is, several different jobs run together in a single form and printed on the same sheet to be subsequently cut apart.

Special presses. There are numerous variations on the types of press described above, including presses designed for specific repetitive jobs or for a specific type of work, but the three described, rotaries, flat-beds, and platens, are the types in wide use for general printing.

A specialized form of relief printing used for the printing of bags, food wrappers (including bread wrappers), acetate, cellophane, waxed papers, metal foil, and other materials having surfaces not easily handled by ordinary letterpress methods is aniline printing, now more generally known as flexography. The earlier name came from the fact that aniline dyes were (and are) used for pigment in the inks. The inks are liquid, dry quickly, and because of their use on paper and other substances that are directly in contact with food, must be odorless. Printing is done from flexible rubber plates carried on the printing cylinders of web-fed rotaries. See PRINTING PRESS.

PLANOGRAPHIC PRINTING

Planographic printing is printing from an even surface—one in which the printing portions are neither above the nonprinting portions, as in letterpress, nor below the nonprinting portions, as in intaglio.

A second distinguishing feature is that the process (lithography), by which all but a very small percentage of planographic printing is produced, *is based on the simple fact that grease and water will not mix.*

Lithography, the invention, possibly by accident, *of Alois Senefelder, dates only from 1798, nearly 350 years after Gutenberg. The term means literally* stone writing or stone printing, and for the first 100 *years of its existence most lithography was just* that.

Direct lithography. In the original process the copy to be printed (lettering, music, or artwork) was either drawn by hand in reverse (right to left) on the surface of a slab of porous stone with a greasy crayon or in greasy ink, or was transferred to the stone by rubbing, having first been drawn with a grease crayon on transfer paper having a special surface. The surface of the stone was then sponged with a solution of gum arabic in water to render the nonprinting portions receptive to moisture but repellent to greasy ink and the printing portions receptive to grease but repellent to moisture. The surface, after being dampened with water, was then rolled with the greasy ink, which adhered only to the printing image; paper was laid over it and a print made by pressure.

This process, known as direct lithography, is little used commercially today, but survives as a fine arts process for the making of lithograph prints made from drawings or lettering done manually on the stone and printed on a hand press.

Indirect lithography. The lithographic process, however, not only continues but flourishes in the form of indirect lithography—offset lithography (offset for short). The heavy, clumsy stones have been replaced with thin, flexible metal plates, usually of zinc or aluminum and usually with a fine-grained surface (although nongrained plates are also in use); the slow, stop-and-start flat-bed presses on which the stones had to be printed have been superseded by presses having a continuous rotary motion; and photographic methods have almost entirely supplanted the old manual and hand transfer methods of putting the image on the plate.

Although offset has not as yet caught up with letterpress and rotogravure in the printing of metropolitan newspapers or nationally circulated magazines (experimental work toward that end has been in progress for several years and is still in progress), it is being used for almost the entire range of commercial and advertising printing, including window and counter displays, posters, road maps, packages and container labels, and picture postcards. It is also being increasingly employed for books, book jackets, and for pull

u of m ll or mode ate c rculati n and n con j t n th c ld type (t pe p od ced on ma hi ope at ng o the typewrit r pri ciple as pposed t h t m tal type) it has t ken o r a vast m f pr nti wh ch budgetary m de a n a e p r m u t In th new paper fi ld s vet, ts use ha been o fi ed to a n mpa at ly m ll mbe of e kl es a d a few m ller-city dailies

Off t p ses In e n tr ctio and oper ting prin ple, offset p e d ffe widely fr m thei lett rpres m te pa t The typ cal p e ntai n l ur cyl d of n fo m d met r Th d am t r and th l ngth of the cyl nde s ry w th the e f pl te to b handled Fi t f the fo r s th print ng l d b ch a r es th fl tible met l pr nting p e clamped tightly ar nd it Be ri g on th e on ea h de of the cyl nde re two s ts f Th the w t r ller which mo t n th face f th plate s the cyl d r l and the i k ll s wh h supply the nk He e again th f s a d water p ciple appl s the wat r is retained the nonp nting pa t of th plate b t ru ll th g e y pr nt ng image, wh le th e image h ld th k h h is l o gr a y but r p l th ter

Th p i t g cyl nder tw th ta d ng ts nam doesn t p t th m g on p pe in f t t neve u t t with th pape I t d it p nt th im g o the rface f the sec nd yl d r an intermed te cyli der kn wn as the r l b r bla k t luud becau ts surf ce rubb r Th cyl d gen ally l c t d bel w the p ti g cyl nder dust g tto r

T d (u ally) of the bb r bl k t cylind i the th rd cyl der th impre ion cylin der th p p e f h h as i lett rp e s tary n u h ld th pap aga n t th bbe ll nket eth d r a the yl d r n lve Th pape i th f m f th l ts r web (th ar b th he t fed a d b-fed ff t t) *fe d* betw n the imp es n cyli d nd th rubbe bl k t lind and p i ti g take pla t th point t hich th tw a e co ta t Thus the p nting im g i tr f d t o ff et o th p p nt print d d rectly *it by the pri t g plat h n* th t rm ff et a d d ct l th gr phy Th fourth l d h h s u lly l elow the imp ion cyli der and revol sga n t t i the d l y d ere d f the p s

Lik th l tg l it p e r tar es m ff et p ma be mad up of veral pr t ng nits Th p d gned f f r lo p o e p t m h f r n t in ta d m e p nt ng the l o th r d o e the blu nd e th bl k th col b ng pri ted *c s* ly (lth ugh n t b c l that o der) o the h t web it m gl l r and t o-col m d l Attempt h b a m d f m time t e me t der m f nt med m (rubb bl k t) cyl f p t g d m *f om plate to p pe*

As yet howev r it continues to hold its place mainly f r the rea on that ha ing an el stic in tead f ri d n t l u face it can print h lftone e n fi e-c e n halftone on rough n faced paper n m tal (as in th printing of tin) and o the une en s rfac s including canvas wo d and l ath r Thi i e tl er me h nically impo ble or c mm r ially mp actical with letterpre s It al c ntributes t at lea t doe not interfere w th tl e c nt n i us r tary m ti n of the p ess and w th albumen plates partic larly may c ntrilute to the life of the plate by enabl ng tl e photo-graphically imp nted im g t tand up long r on the pre s than t w uld if in direct conta t with the paper

D y ff et p o e s Dry off et i a pro e wh ch employ th ff et p inciple but in wh h th plano graph c p nti g plate s replac d with a plate having the image i r l ef the by eliminat ng the n ed f r the wate roll rs wh h on cca on ha e be n the s urc of p duction d ffi ult e Altho gh this p cess t g ally a ailable it h ld def n te po s biliti fo th fut r

Planographic composition Offset p ducti n d ffer from letterpre pr d t on in e al re pect beg nning with ompos ti n If type p o-duced n hot m tal m hin s i t le u ed the typ t pr d read and o rected as in letter pr after wh h repr pr fs (pr f for photo g aph ep od ti n) a e taken The e pr fs are usually pull d n a o ted or d ll c ated p per on a spe al typ f p o f p a d are as ne rly perf ct mechanic lly a it is p sibl to make them If ld typ c mp tt i t be u ed th py i typ d on m th rfaced wh t pape eithe n typ w t o ne f the seve l old t pe mpos n m chi es and th typed she ts r u ed n th s me manner a r p pr of

In th next tage the r p p fs or typ ed he t r t up nd p t d down t geth r usually with ubbe em nt n a c efully l d o t sheet w th b dy tt h d d c pti n in th exa t po t n they e t c upy the pr nted p du t th esult b i g wh t kn wn a a k yl ne l yout or mo e often i the t ad a r ch cal Such me hanic l may ns t f a s gl page a pre d (two f g pag) r f 4 8 12 16 o more p ge arr g d a n a form l tte pres Line llu trat n f dr wn t the p per al m y be mo nt d n p ition n the m chan c l f to la ge f r tf th y may be phot gr phed d wn (red d) t the prop r si e nd the ph togr phi pr t mo nted in pl n t ad e eparat lin neg t may be m d Sp c t b c upi d by halft e a e th r l d ll on th m hanc l o a i d c ted w th re ta gl of bl k pap r c t to th ct s the h lft a e t be nd m unted in the r al p s t

Meanwh l if ph tographs wa h draw g or oth t nal rt wo k r t be ed a ll t ati they a e phot graph d s pa tely th gh a half t ne s reen d h lft e neg t es made All neg ti e both halft ne nd l ne ar efully

which carry it to the delivery end of the press and deposit it on the sheets previously printed.

Presses of this type are also known as cylinder presses and in most cases require two revolutions of the cylinder for each impression.

The sheets produced on flat-bed presses, after being printed on both sides, are folded by machine (or sometimes by hand) into signatures of 4, 8, 16, 32, or more pages with pages in consecutive order and the signatures subsequently trimmed to a predetermined page size. A printed piece such as a booklet or catalog may consist of one or several signatures, the latter held together by wire staples, thread (as used in books), or wire, plastic, or other mechanical binding.

Flat-bed presses are made in various sizes and models, including some that operate vertically. They do not have the speed of rotaries, production ranging approximately from 1500 or 2000 to 6000 impressions per hour, depending upon size of sheet and nature of work, but they are far more flexible in terms of short and long runs, different sizes of sheets, and ability to handle a wide range of work, and cost less to purchase and to operate. They are in general use in commercial printing plants and are capable of turning out a wide range of high-grade printing.

Platen presses. Small printed pieces such as envelopes, postcards, stationery, circulars, and small business forms are usually printed on platen presses—the familiar open-and-close or clamshell action type of press common to printing plants generally, particularly the smaller ones, and generally known as job presses. They may be either hand or mechanically fed. Or, if required in large editions, these smaller pieces may be printed on large sheets from two, four, eight, or more identical type forms, plates, or sets of plates, the sheets being later cut up into the individual pieces. Often also such jobs may be ganged up, that is, several different job runs together in a single form and printed on the same sheet to be subsequently cut apart.

Special presses. There are numerous variations on the types of presses described above, including presses designed for specific repetitive jobs or for a specific type of work, but the three described—rotaries, flat-bed, and platen—are the types in widest use for general printing.

A specialized form of relief printing used for the printing of bags, food wrappers (including bread wrappers), acetate, cellophane, waxed paper, metal foil, and other materials having surfaces not easily handled by ordinary letterpress methods is aniline printing, now more generally known as flexography. The earlier name came from the fact that aniline dyes were (and are) used for pigment in the inks. These inks are liquid, dry quickly, and because of their use on paper and other substances that are directly in contact with food, must be odorless. Printing is done from flexible rubber plates carried on the printing cylinders of web-fed rotaries. See PRINTING PRESS.

PLANOGRAPHIC PRINTING

Planographic printing is printing from an even surface—one in which the printing portions are neither above the nonprinting portions, as in letterpress, nor below the nonprinting portions, as in intaglio.

A second distinguishing feature is that the process (lithography) by which all but a very small percentage of planographic printing is produced is based on the simple fact that grease and water will not mix.

Lithography, the invention, possibly by accident, of Alois Senefelder, dates only from 1798, nearly 350 years after Gutenberg. The term means literally stone writing or stone printing, and for the first 100 years of its existence most lithography was just that.

Direct lithography. In the original process the copy to be printed (lettering, music, or art work) was either drawn by hand in reverse (right to left) on the surface of a slab of porous stone with a grease crayon or in greasy ink, or was transferred to the stone by rubbing, having first been drawn with a grease crayon on transfer paper having a special surface. The surface of the stone was then sponged with a solution of gum arabic in water to render the nonprinting portions receptive to moisture but repellent to greasy ink and the printing portions receptive to grease but repellent to moisture. The surface, after being dampened with water, was then rolled with the greasy ink, which adhered only to the printing image; paper was laid over it and a print made by pressure.

This process, known as direct lithography, is little used commercially today but survives as a fine art process for the making of lithograph prints made from drawings or lettering done manually on the stone and printed on a hand press.

Indirect lithography. The lithographic process, however, not only continues but flourishes in the form of indirect lithography—offset lithography (offset for short). The heavy, clumsy stones have been replaced with thin, flexible metal plates, usually of zinc or aluminum and usually with a fine-grained surface (although nongrained plates are also in use); the slow stop-and-start flat-bed presses on which the stones had to be printed have been superseded by presses having a continuous rotary motion; and photographic methods have almost entirely supplanted the old manual and hand transfer methods of putting the image on the plate.

Although offset has not as yet caught up with letterpress and rotogravure in the printing of metropolitan newspapers or nationally circulated magazines (experimental work toward that end has been in progress for several years and is still in progress), it is being used for almost the entire range of commercial and advertising printing, including window and counter displays, posters, road maps, packages and container labels, and picture postcards. It is also being increasingly employed for books, book jackets, and for p[illegible]

t ns of m ll or m de ate c ul t o and in con t u th ld t p (type prod ced on ma ch es ope at n n th typewr t r pr ncipl s opposed to h t metal type) it has t ken e a t m of printin in wh ch b dgetary con dera n are pa am u t In the newspaper field as yet, it u e has been confined t a comp rati ely m ll numb l e klie and a few maller-city dail

Offset p esse In n t u tion and perati g pri c ple ffset p es e d ffe w dely fr m the r le pres counterpa ts Th typ l p c nta ns l e Y d l un f rm d ameter Th d ameter a d th length of the cyl nd rs ry with the ze of pa t b h nai d F r t of the f r is the pri t ng l nd h ch rries the flexible m t l pr nt n pl te l mped t ghtly r und t Bear ng n th s ne h s de f the ylind r a two ets f r ller the ate r llers wh h m isten the fa f the plate s the yl nd r lve a d the i k rollers, h k s pply the i k He ag in the gre se a d t prin ipl appl es the wate is re ed on the n npr nting p rts of th plate b t r ff th gr y p i t ng im ge while the ima h ld th k hich i l gr y b t repel the wa

The pr nt g cyl nder notw th tandi g its n me doe n t p int the im ge on p pe in fact t ne er t mes in conta t w th the paper In te d t pr ts th g on the face f th s ond ylinde an intermediate yl nd r k wn the r bber bl nket c l nder beca its s f e s ubbe This cyl der gene lly locat d b low the pr nt g cylind r k d ta nt t it

T ne d (sually) f the rubb r bl nket cylind r is the th rd yl d r the mp e s yl n d the pu p e f wh h a n a letterp s r ta y a t h ld the pape ag inst th rubber bl nket ri h d s the cyl der ol e The pape in th form f eth r h et web (th a b th he t fed d w b-f d off-et p e) f ed s betw n the imp es cyl nder nd th r bber bl ket u der a d p i t ng t ke plac t th point at hi h th two n t ct Thu th pri ti g m g is t n f rred t r offs t on the p per not p nt d d tly on it by th p i t ng pl te h n e the terms ff t and d re t f th gr phy The f th cyl d r hi h i lly bel w the mpr s n cyl d and e ol es gain t t s the del ery de i th pr nted sh et o w b t the d f tr re d of the p

Lik th l g lett p e s r t r es an ff et pre ma b m d up f sever l p inting u its Th s a pres d gn d for fo r lor p ce p i t g may h fo un ts in tand m n pr nt ng the the red the bl e and o th bl ck th l s k ng p ted ucces ely (lth gh n t ne es ril th t o d) th h t or web a t tr l thr ugh th pre S m lle pre s are mad n l and two-c l m d ls

Attempt hav be made f om t me t time t m the nt rmed ate (rubbe blanket) cyl n der a d or f p i t g d rect fr m plat to p p r A yet howe r t continues to hold its pl ce mainly f r the r a n that having an ela tic in stead f a rig d m t l surfac it can print halft nes e en fin sc een halft nes on rough urfaced paper on metal (as in *the print ng f tin) and* on other uneven su f ce in l di an as w od *and leathe Th s is the* m chanically impo ible r omme ally impractical with lette pre s It al *co t ib te to or at lea t doe not* interfere w th th ontinuou r tary moti n f the pre r d with albumen plates pa t cula ly may contribute t the lif of the plat by enabl ng the photo-graphic lly impr nted image to stand up longer on the pr s than it w uld if n direct conta t with th paper

Dry offs t p cess Dry ff et i a proc s which empl ys th ff t princ pl but in wh ch the plano-g aph p inting plate replaced w th plate ha ing the mag in relief the eby eliminat ng the need for th water r ller wh h on o cas on have b e the our e f p oducti n d ffi ultie Alth ugh th s pr is ot g nerally a a lable it hold definite po bil ties for the futu

Planographic composition Off et produ t n d ffe fr m letterpre s product on n e e l e spects beg nn g with comp s t on If type pro du ed hot m t l m ch es s to be u ed the typ t p d re d and corre ted as in letter p ess afte wh h repr pro fs (proofs for ph to g aph r pr ducti) r take Th e pro fs are u ually pulled a co ted or dull co t d paper on pe i l type of pro f pr s and re as nearly perfect me hani lly a t s p ibl to make them If old type" c mp t on t be i ed the c py typed m mo th su fa ed white paper eithe on typ wr t r o n ne of the se e al "c ld type ompo in ma h ne and th typed heets a u ed in th me m nner a rep proofs

In th next stage th ep o pr f or typ d she t e c t up and past d dow t g the u ually w th f b r ement c refully la d o t h et w th b ly m tte heads nd capt n n th ex ct posi t n they a e t c upy n th p t d product th re ult b ing wh t i k own as keyl n layout m re ften in the t ade as a m chani al Such m han ls m y nsi t of a ingle p ge a p ead (tw fa i g pag) f 4 8 12 16 or m e p ge a r ng d n a form n l tt pr s Line illu t t on if drawn t the pr per s ale m y be mou t d in po it n the mech nical f to la ge f r th they may be ph t aphed down (redu ed) t the pr p r a d th phot r phic prints m nted in plac in te d r sepa at l ne n gati es m y be nade Spa t be o cup ed by h lftones ar e th uled ff o th m h c l r are in dicated w th recta gle of bla k p p ut t the ex ct ize the halfto es ar to be and m unt d th i e al po t ons

Mea wh le if ph togr ph wa h dr w ng r other tonal t work a t be ed a ll tr t on they re photog aphed s p r tely thr ugh a h lf t n een d halft ne n g t m de All n g t s both halftone and li a c fully

which carry it to the delivery end of the press and deposit it on the sheets previously printed.

Presses of this type are also known as cylinder presses and in most cases require two revolutions of the cylinder for each impression.

The sheets produced on flat-bed presses, after being printed on both sides, are folded by machine (or sometimes by hand) into signatures of 4, 8, 16, 32, or more pages with pages in consecutive order, and the signatures subsequently trimmed to a predetermined page size. A printed piece such as a booklet or catalog may consist of one or several signatures, the latter held together by wire staples, thread (as used in books), or wire, plastic, or other mechanical binding.

Flat-bed presses are made in various sizes and models, including some that operate vertically. They do not have the speed of rotaries, production ranging approximately from 1500 or 2000 to 6000 impressions per hour, depending upon size of sheet and nature of work, but they are far more flexible in terms of short and long runs, different size of sheet, and ability to handle a wide range of work, and cost less to purchase and to operate. They are in general use in commercial printing plants and are capable of turning out a wide range of high grade printing.

Platen presses. Small printed pieces such as envelopes, postcards, stationery, circulars, and small business forms are usually printed on platen presses—the familiar open and close or clamshell action type of press common to printing plants generally, particularly the smaller ones, and generally known as job presses. They may be either hand or mechanically fed. Or, if required in large editions, these smaller pieces may be printed on large sheets from two, four, eight, or more identical type forms, plates, or sets of plates, the sheets being later cut up into the individual pieces. Often also such jobs may be ganged up, that is, several different jobs run together in a single form and printed on the same sheet to be subsequently cut apart.

Special presses. There are numerous variations on the types of press described above, including presses designed for specific repetitive jobs or for a specific type of work, but the three described, rotaries, flat-beds, and platens, are the types in wide use for general printing.

A specialized form of relief printing used for the printing of bags, food wrappers (including bread wrappers), acetate, cellophane, waxed paper, metal foil, and other materials having surfaces not easily handled by ordinary letterpress methods, is aniline printing, now more generally known as flexography. The earlier name came from the fact that aniline dyes were (and are) used for pigment in the ink. These inks are liquid, dry quickly, and because of their use on paper and other substances that are directly in contact with food, must be odorless. Printing is done from flexible rubber plates carried on the printing cylinders of web-fed rotaries. See PRINTING PRESS.

PLANOGRAPHIC PRINTING

Planographic printing is printing from an even surface—one in which the printing portions are neither above the nonprinting portions, as in letterpress, nor below the nonprinting portions, as in intaglio.

A second distinguishing feature is that the process (lithography) by which all but a very small percentage of planographic printing is produced is based on the simple fact that grease and water will not mix.

Lithography, the invention, possibly by accident, of Alois Senefelder, dates only from 1798, nearly 350 years after Gutenberg. The term means literally stone writing or stone printing, and for the first 100 years of its existence most lithography was just that.

Direct lithography. In the original process, the copy to be printed (lettering, music, or art work) was either drawn by hand in reverse (right to left) on the surface of a slab of porous stone with a grease crayon or in greasy ink, or was transferred to the stone by rubbing, having first been drawn with a grease crayon on transfer paper having a special surface. The surface of the stone was then sponged with a solution of gum arabic in water to render the nonprinting portions receptive to moisture but repellent to greasy ink, and the printing portions receptive to grease but repellent to moisture. The surface, after being dampened with water, was then rolled with the greasy ink, which adhered only to the printing image; paper was laid over it, and a print made by pressure.

This process, known as direct lithography, is little used commercially today, but survives as a fine arts process for the making of lithograph prints made from drawings or lettering done manually on the stone and printed on a hand press.

Indirect lithography. The lithographic process, however, not only continues but flourishes in the form of indirect lithography—offset lithography (offset for short). The heavy, clumsy stones have been replaced with thin, flexible metal plates, usually of zinc or aluminum and usually with a fine-grained surface (although nongrained plates are also in use); the slow, stop-and-start flat-bed presses on which the stones had to be printed have been superseded by presses having a continuous rotary motion; and photographic methods have almost entirely supplanted the old manual and hand transfer methods of putting the image on the plate.

Although offset has not as yet caught up with letterpress and rotogravure in the printing of metropolitan newspapers or nationally circulated magazines (experimental work toward that end has been in progress for several years and is still in progress), it is being used for almost the entire range of commercial and advertising printing, including window and counter displays, posters, road maps, package and container labels, and picture postcards. It is also being increasingly employed for books, book jackets, and for pull

ble m rg the newe t ha g c me into gene l se m th United St te in 1912 Its in ent o o t le st t appl cat t the print ng of paper (the flat p n ipl h d bee mployed e l er f lithogr ph p i t g on t n) s j tly c d ted t Ira W R b l d t the H rr s b thers A F and Charles Rubel a d the H rrise work g ep ra ly a d nd p nd tly appe t ha rived t p ximately the me re lts at appr xim t ly the a e tim Like Senef lder s i ention f l thography the m e t of ff et m y ha e bee at least partly a de tal

Alth gh the t t l ol m f work p d ced by lith gr phy i st ll materially bel w that prod c d by letterp es its pe ce tage i ease h s be very much h gher 105% as aga nst 38% fr m 194 to 1954 Th i se n l m o e the me period t taled $665 000 000 f l tterp ess a d $ 00 000 000 for l th graphy In g av e wh h m th d i total ol me th pe ntage increa e from 1947 to 1954 w 205% the olume increa e $114 000 000

PHOTOGELATIN PRINTING (COLLOTYPE)

A p oc h ch belong in the planogr ph cate ry alth gh t l te ally pl g phic i ph t g l ti p nt g coll type a disti gui h g chara te t f h h is th t t u een In r mod rn e o —it ion lly was mainly a hand p oc i wh h pr d cti n m ght m t ten m e th n 100 mpre ns p day—the pl te lly of l m um s c ted w th a laye f l ht sen iti (b h om t d) gel t o e wh h had an nsc e ned phot or phi negat e of the p t be p od d Wh the two ar e p ed to light the g l t ffe t d arying deg e in p portion t th m unt f l ght dm tted to it th ough th d k m d m a d l ght p rti s f th neg t The pl t n f rther t tm ts m l d g imm r n a gly e oluti d the end es lt is p i ti g im wh h a ot only m th k es (i terms f th sa dth f l m) b t m mo t nt t d c q t b l ty to rep l nk h ld t ry g am t The plat i k pt m st d th p e om m nta ed at th p ope degree f h m d ty by ca f lly t lled h m d fi at n

Ph t g l t n r llotyp i es e t lly h t run p oces r ns f nly a few h nd d p t e comm th 5000 t p h ps 10 000 a pra t l m xim m, but i u d f f ly w de ra g f f rr ng k i both bl k a d whit d ol m l d g unt r d pl y p t bl w ps (largem nt) f d rt me t d p t l c py and f m l rep odu t s of phot g ph Be ra f t sc le n t h bee u d t gre t t f t i rep duc ng a t m us r pts h th th e f ll ng t e f om g r w Ea l t ff f m ha d l g d p r to the rar Of ll p oc es it g o i p bl f gi g the m t f th l f m le rep d t

Pri t g f rm l y d top-cyl d p se from flat pl tes f h a y gla s n w d e

sheet fed rot e P d ction sp eds v ry accord i g to the n t re and s e f the py and the sur f e on which t is to be pri ted

INTAGLIO PRINTING

The p re tal p e s in inta l printing (pro fessi lly pronou ced in taggl i) is steel and coppe pl te engra g which ri al l tte p in age g i g back i Europe m le st as fa the t me f Gute be d p obably farther and i China possibly t the time of P Sh ng Acc d t D Updik the first book d rated with c p p rplates wa p inted as e ly a 1477 (Gutenb g died in 1468) and books with c pperplate p ct and t tle pages we e fa ly ab indant in the late t e th and the e tee th centuries

Engraving In th proce s the t st t k a thi but ri d pl te f c pper o steel d ew sket hed his p ct re on it usually i r ght to left rever d th n cut the l es f the p ture and of the l tters g if any int the fa e of the metal with a small V po t d gra er or burin After the cutt g was c mplet d the plate was i ked it t e face a d then wiped s th t th i k w rem d from the s f ce b t was retained in the m ed engr ed l es This is the gin l and l teral meaning of the term whi h t d y is appl d ge lly t relief plates in both l n d h lft e Paper is then la d e the plate pap r and plate e i ert d a cr de form f hand p e s d th ink is t ansferred from engra ed lines t pape by mbi ti n f p ssu e and tio

Alth gh t s e t ly m t t d by form f raised printin the oce s survi es today n the m k f pl t f r f rm l call g d eng ed tati ne y f m l m t such a w dding tat ns ertai forms of cert fi t s and in rt t t h I the l t th su fa f the plate s usu lly co ted w th wa and th d aw ng done i the w x w th a sharp-p t d in tr ment wh ch p et te th gh t th ppe Th aft r th pl te t h d w th d th l es b g b tten d wn to tl e met l th w x which p te t the nonp ting p rts f om the acid mo ed and the pl te is ked w ped d pri t d

Int glio p i ting from teel pl tes i ed n the reau of E gra i g and P t g i Wash gt n fo the print g of paper m y (ex pt f the e ial numbe ng wh ch d lett p e) nd t mp

Gravure processes O t f th b tr d t al t h q h e g wn the th ee p c s wh ch t day kn w llecti ly gra ure—ph to gra rot gr a d h t f d gra u e Of these the la ge t d th m t imp rt t m m lly tog a wh h d fr m l ge gra d pp f ced copp ja ket d yl n de s c rr ed n w b-fed p ses f the ta y t pe d ed f r n w p pe to t o f me f th b g d tion m g zin d f b g d t on mme ci l w k (*This We k* maga *The Ameri Weekly* th Sund y m g a d book

inspected on a light table and any pinholes or other imperfections are opaqued out that is painted out with an opaque purple or black paint on the negative

Planographic plates In letterpress separate plates are made from the halftone negatives In offset the halftone negatives and the line negatives of type and line art are assembled and taped down together with transparent gummed paper on a flat the negatives being positioned exactly as the type and pictorial matter are to appear in the finished product The flat is a sheet of opaque paper usually colored on which a careful layout corresponding to that of the mechanical has been made and openings cut for the line and halftone negatives that are gummed down on it so that the paper partly masks out the nonprinting portions In other word the flat i a composite negative made up of the negatives of all the material both typographic and pictorial that is to appear in the page spread or form as the case may be In color work a flat is made for each color the flats being carefully registered one with another

In all negative whether line or halftone the black and white values are rever ed Type proved in black ink on white paper for instance will appear white and transparent against an opaque black background in a negative

Preparation of plates The flat i next laid over the flexible metal plate the surface of which has previously been coated with a light sensitive emul sion (pre ensitized plates are widely used in offset plants) and the two are locked together in a vacuum printing frame These vacuum printing frame come in several forms a common one being similar to a large table with a steel framed gla s top hinged on one side this top is rai ed the flat and plate in erted the top locked down and the air ex hausted to ensure perfect contact between flat and plate The image is then burned in with powerful lights which hine do vn through the negati es to the plate hardening the emulsion under the trans parent lines and dots and rendering it insoluble in water Nonprinting areas which are shielded by the opaque parts of the negatives are not affected by the action of the light and remain soluble

After exposure which varies in length of time according to the nature of the work to be printed the flat and plate are removed from the printing frame and eparated the face of the plate is coated with a special ink and the plate is then washed The ink adheres to and brings out the printing image but wa hes away from the nonprinting areas carrying the emul ion with it and leaving the metal expo ed The printing image is then fixed and subject to final change or correction the plate is ready for the pres

When the flat has been completed but before it is put into the acuum printing frame a photographic print is made from it u ually on blueprint paper or its equivalent inexpen ive photographic papers are u ed which can be developed in water This print folded down into a signature with pages in consecutive order is the equivalent of a final proof on which the author editor or production manager may within limits indicate his la t corrections or mark his approval

Deep etch plates The procedure described above applies to the making of albumen plate in which egg albumen is the vehicle that carries the light sensitive alts and which are widely u ed For sharper contrast and greater detail in halftone however and particularly in the more exacting forms of color work the off et printer may make use of so-called deep-etch plates For the e photographic positives instead of negatives are used in the flats and the printing image is etched lightly below the surface of the plate thereby enabling the plate to carry more ink than is mechanically possible with albumen plates Deep-etch plates are also more durable than albumen plates The term deep in this connection is a misnomer actu ally the depth of etching is o slight that it can barely be felt with the fingernail and the plate is classified as planographic although in fact it is slightly intaglio

A special form of deep etch plate the bimetal plate has come into u e in recent years The e plates are compo ed of two metals one of which has a special affinity for water and the other for ink the former constituting the surface of the plate One combination used is a wash of chrome over copper In this the image is etched through the chrome to the copper thus taking ad antage of the special qualities of the two metal There is al o a trimetal plate of chrome over copper backed up with steel or zinc

For use in the flats for deep etched plates repro proofs are sometimes pulled on thin heets of acetate on a special pre s which prints the image in exact register on both sides of the acetate to ensure opacity and these acetate sheets are u ed in the ame way as photographic po itives Similarly the negatives or positives of type matter produced on the phototype etting or photocompo ing ma chines may be used in the making of flats or of mechanicals This eliminates the tep involved in the making and photographing of repro proof

Place of offset lithography It has been men tioned that in letterpress jobs running to very large editions may be printed from two four eight or more identical plates or ets of plate u ually electrotypes with a corresponding reduction in press running time required In off et the equi a lent of this duplicate plate technique is obtained by mean of the tep and repeat machine whereby identical image precision paced at fixed d tances apart (both sideways and up and down) may be projected photographically onto the ur face of a single large plate With thi de ice ets of large color plates carrying multiple image may be made which will regi ter exactly plate to plate and image to image when the color are pri ted succe i ely one over the other

Of the three major printing proce e —letter pre s off et and gravure—offset is b y a con ider

special container The plate is then heated to bake in these particles on the s f ce of the metal the particles forming the equi al t of an acid r sta t screen or gr patte carb n t car ying a photograph po t e is placed in p tion o er it and the pl t is etched in much the same way as a plate for sheet fed gravure P d t on done on a hand press will ru in 100 ev n few r sheets per day

SCREEN (STENCIL) PRINTING

Of the stencil printing processes referred to ar ll e a e tw that should be mentioned here mimeograph and silk screen printing Th f rm s a t lly a c py g d pl t g ather than a printing process although capable f producing up t perhaps 5000 copies d is widely k n th gh its u i b si e s offi es a d m li tary rel The t il i n ually typed on a typewriter Lettering diagr m a d d awn may be dded by d a i g t r c ng them n th stencil with styl s M ny mall p bl cat ns h s church and company new l tt s nd an normo s ariety of l blic ty ha d ts and m ell eo h t r n c py f all types re ha dled by this technique B th te l utting and printing can be do by offic help m king it o e f th most ec m l f p o e es

More important f m a p t g ll dpoi t th silk screen process wh ch d for a wid variety f ad rt i g clud g p st wind w nd unt d plays d th l k nd fo pr t g n wood m t l l th pl t c d oth onpaper surf es It l find se s a fi e arts pri t p oc nd h m y thusi ti do t y rs lf prac ti E t ally the pr e s co s t f a screen, usu lly f 51 gage lk n wh ch by ny f l techn qu d s g t c d o lett red and th n p t g p rt nted r with n k and w t res tant l cq e Th sten l is tried tightly t tch d a f me th ink wh h a t lly i a paint r the than a k i armed th am f m nd by mea f squeeg th k is p lled ba k a d f rth in th frame, p t g t h pull mp e i n on the paper or th r su f wh ch i held p s ti on a tabl nde th the f am P i t g is s lly d e i flat p q l rs o e c lor t me Prod ct n by m nu l m th d s sl w o ly a few h d ed impr ns pe ho b i n p wer-d e presses of h h only e mp r t few a t present u th can b mult pli d e er l times P b b l i re that th e s will b ery considerably exp nded th n ar f t d th t method n w in p oc s of devel pme t w ll lead ent lly t the eq i l t f halft pr nt ng by its process. [L B S]

B l g phy Ameri n Phot ng a ers A s ci tion, Th A t of Ph t e g i g 1952 T F G Th l t f P ti g n Ch a d I Sp eed g tu d 2d d 1955 B D lg n Ad rtis g P d t A M l n th M Lenact of New pap P i t g 1946 T e r The Power f P i t and Me 1936 L. Flader nd J S Mertl Mode n Phot e gra i g 1948 O W F hrm n Gut nber and the Strasbo g D cu ments f 1439 1940 L C Ga dy Th y l lith graphy Lith raphers Journ l suppl 1940 G aph c A ts Prod ction Y rb k 1959 D Hymes Prod ctio in Adverti sing and the Graphic Art 1958 D C. M Murt ie The B k 1937 Melche and N Lar ick P ting nd Prod ction H db k 2d ed 1956 G J M lls S u c s of Info mation in the Ame c n G aphic A ts 1951 J C wald A H i ry of Pri ti g Its Development through F ve Hu d d Ye 1928 The P nr se A n l 1959 T Stanl y The Tech que of Ad rti ng P ducti o 2d ed 1954 A A Sutt n D sign and Makeup of the N w paper 1948 D B Updike Printi g Types Th Histo y Fo ms a d Us 2 ol 2d ed 1937

Printing in color

The art nd c aft of embell hi g de igns pictur and typographic pages f a m e ple s ng effect th n btai ed n bl k and wh t add tion f r p ctu es wh h more e rly r prese tati e f the or gin l obje t p int ng L g bef e printed p ges suppl ted h d writt n ma pt sc ibes ornamented their p ge w th elab rate de orat o s (o br cs f om the red lo s fte appl ed to titl s a d n t al letters) Ea ly p inti g lso h d ll st tio s t nt d c l by h nd Wallpaper painted n c lo s d tes ba k t 200 B C whe the Ch e decor ted r e p p r with b d fl w s and l nd capes

After the de elopme t f l thog phy by A Se e felde b t 1798 ti t f und t relat ely ea y to pr duce lored p e by wo king di ctly o the l th gr phic sto e u a number of differe t ol to h e e thei ult A pa nter a d t he amed J C L Blon fir t c n ed the po sib l ty of p d ci g w d r nge f col r effe t by us g o ly thr e basi l r He mpt d t ommer ial e hi eff t i 1704 b t th e c l pr nting i the modern en w de eloped ft col phot gr phy I the l te n netee th e tury foll w g the ent n f the halft n sc en ol red h lft w e devel p d Th fir t th e-c l r pro e ll st ti s m lar t pr t d y m thod re ge er lly cr dit d to W Ku tz in 1893 al tho gh mbe f worke s in th field S H Ho ga F E I es d L E and M Levy m d gn fi t t ib t s

Three a d f l r p oc pr ti g cl ely all ed w th ol phot g aphy th f dame t l f lo ep od t o a m h the me fo all th pr t g pr J t s halft nt d n bla k n whit p p i a pt cal ll s o gi ng the l ri th imp n that h i g th i u gr dat n of to e n the g nal ph to g ph a col d h lft n es th ill on that a w d r nge f c l is nt Act ally o ly th e l a e ed (bla k added i th m re mm ly ed f r c l pr c) Th h lfto e

review sections of *The New York Times* and certain pictorial sections of the catalogs issued by the large mail order houses are examples.)

Because of the time required for plate preparation and the relatively high initial costs, rotogravure is essentially a large-scale production process best suited to work that runs into hundreds of thousands or millions of copies. Photogravure is virtually a hand process best suited to limited or deluxe editions in which reproductions of the finest quality are called for, and is capable of beautiful effects. Sheet-fed gravure, which has been more highly developed and is more extensively used in England and on the Continent than here, lies in between. It is suited to runs of moderate or medium length, and its costs are not so high as to put it out of competition with fine-quality letterpress work and with deep-etch offset.

In reproducing photographs and tonal art work the gravure processes are capable of a depth and quality of tone superior to that of any other process, but type reproduction suffers because all matter, typographic or pictorial, going on a rotogravure cylinder or a sheet-fed gravure plate must be screened, and readability of type may thereby be affected. For this reason type matter printed letterpress and gravure-printed illustrations are sometimes used together in the same publication or advertising piece.

Printing surfaces. Without going into the technical details of screen and carbon tissue, it may be said that the printing surface of a gravure cylinder or plate as used for most monochrome work (black and white or, as often, sepia and white) differs from the surface of a letterpress halftone in three particulars: (1) the dots composing the printing image are below the surface instead of in relief; (2) instead of varying in size or area as in a halftone, the dots are all of the same area; and (3) although the dots are of uniform size surface-wise, they vary in depth, this depth being greater or less according as the parts of the copy printed from them are respectively dark or light. For dark parts (blacks or dark grays), in other words, the tiny, almost microscopic cups or wells carrying the ink will be deeper, will hold more ink, and consequently will apply more ink to the paper than will the shallower cups or wells which print the white or light gray portions. (Lest the terms cups and wells prove misleading, it should be said that with the 150-line crossline screen used in most monochrome gravure work there are some 22,500 of them per square inch, and that the depth of the deepest will not exceed 0.002 or 0.003 in.)

It is this ability of the gravure process to print from what is in effect an ink film of varying thickness instead of from one of uniform thickness, plus the ability of the deeper dots to apply more ink to the paper than is possible with other processes, that accounts for the range of tonal values and the depth of tone characteristic of gravure-printed reproduction. Because of the amount of ink applied, the dots on the darker portions frequently spread and overlap one another on the paper, obscuring the screen structure entirely and giving the effect of non-screened continuous tone.

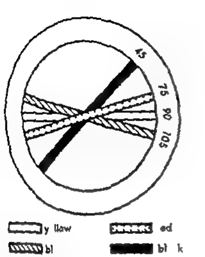
For color work in gravure a process of comparatively recent development is used, the Dultgen or News-Dultgen Halftone Intaglio Process, in which by the use of a reverse halftone screen and two photographic positives, dots are produced which vary in size as well as in depth. This combination of different-sized dots, as in relief halftone, with different-depth dots, as in crossline-screen gravure, while suited to monochrome work, is used mostly for three- and four-color process printing, where it gives added detail, fidelity, and color range to the reproduction.

Printing operations. In the printing operation the gravure cylinder or plate either rotates through a trough of almost liquid ink, entirely unlike the thick, tacky letterpress and offset inks, or has the ink sprayed upon it, the ink being held on the surface as well as in the etched cups. As the cylinder continues its rotation, it passes under a thin, flexible steel blade or scraper, the doctor blade, which extends the entire length of the cylinder, bearing at an angle against it, and wipes or scrapes the ink from the surface, leaving it only in the etched cups. The blade thus does mechanically what the operator does manually in copperplate engraving. To minimize wear and the possible effect of small nicks, the blade is made to oscillate lengthwise against the cylinder. After being wiped, the cylinder rotates further and comes in contact with the paper, which is held against it by an impression cylinder, and printing takes place at that point.

Like the larger letterpress rotaries and offset presses, a gravure press may be made up of several units which may be used either for the printing of additional pages or for color printing. Rotogravure press speeds for monochrome work run around 20,000 or more impressions per hour.

Aside from sheet as opposed to web feeding, sheet-fed gravure differs from rotogravure mainly in the fact that the printing image is usually etched into a thin, flexible copper plate which is clamped around a printing cylinder in much the same manner as an offset plate. As compared with rotogravure, it is a quality as distinguished from a large-scale production process, is much slower (up to 7000 impressions per hour), will print on a wider range of stocks, and, rightly handled, will produce results than can hardly be surpassed by any other process.

Sheet-fed gravure is sometimes referred to as photogravure, but this term is more generally, and more correctly, applied to the intaglio process mentioned earlier, in which the plates are made and the printing done largely by manual methods. Photogravure antedated both roto and sheet-fed gravure. In photogravure, instead of a screen being used in plate making, the plate is lightly covered with fine powderlike particles of asphaltum, an acid resist, which are floated on it by air in a



Scre gl s u d fo -colo p nt g

pr ed over an ther U ually cre n angle are s lected to put the st ng ol r at an angle lea t noticeable to th eye wherea the we ker color is e ed at the angle mo t prono nced to the eye Thus, th bla k pri t ng plate will be made with the dots run ng at an angle of 45 (as i the nor mal bl k and hite h lftone) a d the yellow printing plate w th the dots ve t ally and h r z n tally r 90 M genta nd cyan plate will ha e the d a ngles b twe n the ther tw at 75 and 105 (see llu t a on)

Where nly thr e colors are used the cy n plate will pr b bly be at 45 the m gent at 75 and th ll w at 105 Some pe at r may also prefe to m k th y llow plate with a different halftone rul g to f rther le s n any probl m with mo re pa ern. F r exampl the y ll w pl te may be mad with a 150-line s een nd th othe plates w th the a rm l 133-l n

Angled prints A impl fied method of scr en g p t n (as for coar e scr ened newsp per rk) is f a efully b lanced p siti p ints t be made on photograph p p r f ea h f the se s on eg ti es Th e bl ck and wh te photographs ar t ned to the prop r ngle bef e the c m a and h lft n negat e ar made fo e h If th p t are relati ely mall they an ll be m nted t g th r n f nt of the cam r each t a respect e angle d one h t made of the gro p Th de eloped negati es a e ut part and p nt g pl es m de in the u ual fash n

Deficiencies of pigments In pite f the high le l f fid l ty to the r g al bt inabl in the sep t ons u ing filte s a described n pig m t d es ll pri i ng nks ca pr duce ubtrac tively to the same degr e that filt rs can additi ely The ink f a gi n plate sho ld b th col r complem ntary t th filt u ed f the orre pond g ga Ea h nk h uld b rb o ly on th d of the olo spect um Unf rtu at ly i k t prese tly be manufa t red which will g e al result in th p nt d m ge Each k te ds t l power d muddy up the oth pensate f thus deficienc it ha always been nec e sary to di t rt the epar t on neg ti es by a cer ta n amount of handwork s ch a darkening ome areas and lightening oth r in order to come closer to a facsim le reproducti n f the origi al with the inks at hand *See* COLOR PIGMENT

Color correction masks A new technique called m sking h s gr dually replaced ha dwork to the p int that most colo w rk toda s accompli hed n this manne A ma k is a phot graphic mage uper mpo ed er anothe photo raphic image to alter its transm ssion characteri tics Masks ma be used to change the co trast or to change the c lor balance of the r g nal An operat r may choo e from a numb r f masking methods which may in ol e one or more masks acc rding to the fin l effe t desired Ea tman Kodak C mpany and the Lithographic T chnical Foundation have done a great deal f work on the use of ma ks in colo reproduction

Added color plates Occasionally it becomes neces ary to u e one or mo e extra colo s in addi tion to the standard f ur c lor proce s inks Thi m y be cau ed by a client s i s t nce upon a par ticular olor m tch w th that of his p oduct or in c ses where metallic eff cts are wanted for exam ple bronze gold and sil er Flat c lor ba kgrounds nd bo der are b tte h ndl d by a eparate p int in rather than by attempti g to g t the des red effect with proces pri t ng Lith graph rs for m rly used ext plates as a tanda d pr ct c to nhance the appearance of the final rep oduct on Light ti ts of p nk blue and gray wer c mmonly u ed With impro ed te hn que these extra pl tes a not egula ly employed a p rt of process w rk but add i on l flat colo s re till u ed by all the proc s es

Electronic scanning In 1950 the Time-Life l b rat es wo king with Ea tman K dak Company introduced n le t on de i e fo c n ng c lo transp re es and a tomati ally producing n et f fo r color ep rati n n gat s C rre t n are nc rporat d nto the epa ati ns by the equiv l nt of electr ic ma ki g Sim l r m han ms ha n be n announ ed by ther g oup incl d ng the Acm Colo Separ to the RCA Interch mi al Color Corrector and the Hunt r Penro e Aut s an Thes mach ne work on diff rent prin iple but ll a e u ed in an attempt t speed up and im p o e fo m r means of g tting ol r b lanced pa ati ns f pr cess wo k Although s me ry spe ta ul r e ult ha e be n pr d ced the sca ners ar t yet e dy t be put nto u e verywhe N doubt fut re d el pm nts will m k such m thod mm n h we er th maj rity of c l wo k be ng c rried ut at p s ent as outl ned in th s ar t cle

Short run three color system W thin the l t f w y ars Ea tm n ha developed s mpl fi d method de gn d t p odu olo rep du t on b twe the ph t graph colo prints and the sta d

dots in each color are printed at different angles so that they fall one along side another and overlap to form combinations of many colors Inks for process printing are transparent tones of red blue and yellow *See* INK PHOTOGRAPHY COLOR

Separation negatives *Since three plates (four* for four color process) must be obtained in order to print the proportionate parts of the different colors first steps involve breaking down a colored original into three (or four) separate photographic images These are termed separation negatives In the process the original colored object painting photograph or transparency is positioned before the lens of a large copying camera Over the lens is placed an orange red filter which allows light rays of that color only to pass thus the red portions of the original are represented by tones of gray in the negative In like manner another piece of film is placed in the camera and another exposure made with a green filter over the lens This negative now contains the green portion of the original Again a third piece of film is exposed through a deep blue filter this negative giving a record of the blue areas in the original (For four color process a fourth separation must be made see below) Standard process filters used might be Wratten filters A25 (red) B58 (green) and C5-47 (blue)

Because the light transmitting ability of these filters as well as the sensitivity of the film varies with the color exposures must be regulated to obtain a set of separations which are properly balanced with each other As an aid to the operator for correctly judging the result a gray scale is photographed along with the original This is a strip of paper or film with approximately ten step in neutral shades of gray from black to white In properly exposed and developed color separation negatives the gray tones will match in all three Typical exposures might be for a red filter negative 20 sec green filter negative 24 sec and blue filter negative 6 sec Actual exposures would depend upon the lighting camera settings and kind of film used A transmission densitometer may be used for more exact checking of results

Black printer Although it is theoretically possible to print the full range of tones using only the three process colors most operators include a black printer to add detail and contrast to the printed reproduction To make the separation negative for the black printer the same general procedure used for the other separation negatives is followed As a filter for this separation the best choice (called split filter) is to use all three of the previous filters one at a time with exposures for each running from 50 to 100% of that used for each filter on the individual separations *Experience and judgment will determine* the exact time The object is to eliminate all but the major dark lines and shadows in the finished plate A heavy black printing plate would interfere with clean clear printing of the other colors

Some operators prefer to use a single filter such as a Wratten No 8 (yellow) or other choice depending upon the nature of the subject A black printer separation negative made with a single filter usually requires more handwork for a satisfactory result A third method of shooting the separation for the black printer uses infrared film and a filter (Wratten No 88A) which transmits infrared rays This method will not give best results with all subjects and is usually restricted to paintings and pastel drawings Perhaps the first choice for most purposes is the split filter method mentioned

Screened positives From each of the separation negatives a positive print must be made A positive represents tonal values reversed from those in the negative so the positive made from the red filter negative will represent all colors except red in other words minus red White light minus red leaves blue green the color in which this positive should be printed in process work this color is called cyan The green filter negative produces a positive which must be reproduced in minus green which is bluish red or magenta The blue filter negative in turn gives a positive which must be printed as minus blue or yellow When the three positives are brought together one over the other in exact alignment the original subject is recreated

The steps followed from separation negatives to the combined positive prints vary according to the particular graphic arts process used In the case of photographic prints these positives are prepared on transparent films which are dyed in the respective process colors and the images superimposed to give a color print For offset lithography the separation negatives are each photographed through a halftone screen to give a screened positive from which three deep etch plates are made These plates are printed one at a time superimposed in register in the proper color for the final reproduction In photoengraving it would be necessary to make continuous tone positives from the separations by contact printing then make halftone negatives in the camera after which the photoengraving plates would be made It is also possible in photoengraving to make the separation negatives with the halftone screen in the camera thus obtaining screened separation negatives in the first step Exposures run considerably longer with both filter and screen between the lighted original and the film This is known as the direct method but does not permit as much control as the indirect method outlined above For gravure succeeding operations vary according to the exact system used in conventional methods a special screen is used at the time cylinders are prepared *See* PRINTING PRINTING PLATE

Screen angle As each of the screened shots is made it is necessary to change the angle of the screen ruling This will allow an optical blending of the different colored dots to give the effect of the colors in the original it also prevents a moire pattern which appears when one screened image is

first egati e a lo g expo ure pi ks up all ton except deep hadow f r the seco d negati and med m exp sure r p duces the middle r nge of tones in the third neg t   When p   ti e plate of ea h negat   e printed i   egist r u ing d ffer t tones f k a po t like r p odu t n is th re lt D rk med um, and l ght t   s of the same col printed   a l ghtly t ted pap   fi d gen ral pref erence, b t h rmo zing col r   may   l o be u ed

Split fountain A f   ly c mmo pract e in com l pr t g pl t t   get a   a   ty   f colo s *ated piece i the u e of a pl t f   ntain* Th ink f u t n of th   pr ting p e s is di id d into several   mpartment   wh ch perm ts two o more col s to be   ppl ed t   the paper with one p   thr ugh the p e   As an example a two c lor j b may be run   ith ed   ne h lf f th paper a d bl ck   the oth r half By t rning the she t a *nd f r a c d mpre si n the j b c   be com* pleted ith   h lf the us al tot l n mbe of im p es   Th meth d c n   t be   ed i d cr mi nately th j b must b pl n ed he d f t m   to t k d ntage f th   t i k f the t de

Fluorescence process Ea tm n Kod k intro duced th m thod of p epa   g w tercol r sketch s and th ir s b equent rep odu tio   i   1941 It s iml   t the flu r graph c preparati n   f wa h d *w gs f r h hli ht rep* ductio s n bl ck and h t Spec al p gm   t   r f rn hed i   kits f th art t who proceeds t   pai t   h   n mally The fin hed work w'll fl   es e r glow und ultravi let l ght m k g po   ble colo   ep *o   rrect o   Repr duction* f   regula four   l r proc s routines b t special filters   e u ed The   pybo d i al o s nded w th a   pe i l ho d t   ll w co tr l   f lighti g   ith   white   r ultra olet o   m xtu e f both   n d D t led i   t uct o s *on the pr* ess are   a lable fr m E stm

Variety of modern color printing C l r h t be o m h a epted by the Ame   n p b- that ery l ttle p nt ng   s p od ced with   t olor n o   y or a other The d ly   ewsp p na ally   bla k   d wh te medi m i   beg n e l r At the m me t   nly   n o ad ert   ment   ppe   in c l r but a few per p e   tly t lk f ROP (ru   f the p l r new p p rs w ll p obably   o   jo n gan es   fle ng colo   t   thei ad   t e dern magazines h   e c l r h lft nes   n a ly ery pag   l r ph t graphy w   fi st u ed to l the *Ameri   n M g*   1935 Textbook   n the   d m   ang   r   p d m ll f ee f c l r   ase novel   h *weve*   l ed t th ja k t   m ny of them Childr n book a d g ad sch l book a   filled with col mak th m more attr t

The a r g pe so   m   fac t fac with   l r n hu d ed fo m   whe   he enters t d y drug t   ba d a s t r   or   up rm rket Th   f col   i me cha d   g s   mp rt nt th t ten   t d   h   b en m de of its   b l m l te   n um   Bes des   l   effe t

on v sibil ty it should al o con ey a   imp   sio   of *the characteri tics   f the c ntents* of the pa kage to the vi wer In thi conne tion c lor p inting be comes fu ther n ol ed in the t chnic lities f get t g ink n m ny s   face othe than paper Cello ph ne foil waxed pape   a d plasti   pre ent *p oblem of absorpt on drying* lu ter a d fading Ne erthele s color pri ting n the field   f flexible packag ng a d fold ng boxes is a majo   egment of the gr ph c rt industry

Metal de o ati g   tin pri ting al   has its problem   w th col r printi   M st   f this wo k is done by lith graphy   ing pre e   wh ch take a sheet of metal st aight th ough b tween blanket nd mp ess   cyl nde s w tho t be di   ar und the impre ion cyl nder as   do e w th p per Fo oces   olor   a white   paque backgrou d s fir t p inted a d b ked on the met l   n th   e are s *where the p oc   s col   s a e t* appear

The   are m ny   ther specialty h u es deal n om   and id al w y with col r p inti g Prod cts in   dd t on to tho e touch d upo   here in l de cale d r g eet ng   ds l bels   heet m sic d calc ma ia   pictorial p   t c rd   p ters m ps and fi e art rep od cti ns *See* Printing press

[K R B]

Printing plate

A bl ck   heet of metal wood pl stic   r ther material wh ch arries n ts face a repr ductio   f   de gn dr wing photograph or the art w rk   d whi h wh n pl   d n   p nting press   nd i ked   t a sf rs the   ep oducti n to pap r cloth metal o any other s rfac   apable f r ce i g it I   plate made f r l tte pr   s p i ti   the rep o d ct on   r p i t ng image   i   in el ef I plano graphi pr nt ng   uch as lith gr phy th print ng *im ge s on the   rface of the plate   n a le el with* the   o printin   t ns I   nt gl o pri ti g (for e ample i togra ure) the p i ti g im   i inc   d o etched below th plate   rf ce

Plate for planog aphi and i taglio p nting a e   n d   d sepa ately below under their   pect ve ading

Wood engravings The   rl est f rm   f print g pl te w   th   w   d e g a   wh h s b l e ed t   ha e   at d n Chi a and to h e bee   u ed in b th Chi a a d J p n as ea ly as the eighth ce tu y A D I   E ope t app a s first n th   blo   book of th ea ly fift enth   trury p or to the i   ention of pr   ti g l om mo   ble type   and possibly   a l   th n 1400 The pri t f St Ch istophe   rrying the   l nt Chr st   ros the sw llen t   m pr b bly *the m t fam us   f bl ck p int   i   d t d 14 3* J h nn   Gut nberg did n t mak u e of w od en gr   g   h s page   bei g pr nted f om type a d embell h d by hand but wo d engr   ed   ti l and de r t   s ppe   n b ok p int d by h   u ces   r P S hoeff   a d th r a e w   d engra d l l trat   i books of the l ter fifte nth century

In America w od eng a ing   woodc ts w e w d ly empl yed fo book a d mag zine ll t ation

inks implification of routine automation of opera tions and careful control of all steps are charac teristics of the proce s This Kodak system does not supplant the normal systems but may be indica tive of future developments in the field of color re production

Trapping is a term used in color printing to refer to the ability of a surface to accept ink after an ink layer has already been deposited In normal procedure one plate printing follows another with 6–12 hours between printing If too much time elap es from fir t plate printing to last the ink from the first printings will become so dry and glazed that other colors will not stick or trap In some cases plates are prepared to eliminate under colors where possible in order to permit printing clo e to the paper instead of on top of other inks This is especially true when plates are planned for high speed wet printing for example in shadow areas some of the color is removed letting the black plate carry the bulk of the ink

Two plate halftones Where less co tly means are wanted to introduce color into halftones duotone duographs or duotypes may be employed Duotypes are the simplest form consisting of two halftone plates for letterpress produced from a black and white original both of the plates being made from the same negative but etched differently One plate is etched for detail and printed in a dark color whereas the other is etched for a flat effect and printed in a light color In the printing opera tion the two plates are printed slightly out of reg ister otherwise the darker color would tend to ob literate the lighter one because the screen angles are the same

Duotones and duographs are similar because both are made from a black and white original Two negatives are shot at different screen angles the nega tive for the darker color is shot high and that for the lighter color low or flat Duotones are printed in complementary colors (such as red and green) or in black and a color su h a red blue or green Duographs are printed in a dark and light tone of the same color Duotones and duographs are not limited to the letterpress process as are duotypes There is some confusion in the use of th e terms workers in the trade may use them without regard to the specific meaning

Fake color work The manipulation of black and white reproduction to imitate the effect of proce s color work is called fake color work Four eparate negati es (all alike) may be worked on by hand to get approximate colors in the finished print A widely used material in art and copy preparation for fake color work is the Bourge proces de eloped by A B Bourges in which transparent films in a variety of colors and densities are u ed as overlays for the black and white art work Even relatively unskilled workers can make effecti e u e of the Bourges techniques in the hands of an ex perienced artist the quality of the re ults is good

Blow ups Ju t as enlarged images are used in black and white so blow ups may be u ed in color work particularly by the lithographer After a set of corrected negatives and creened positives has been completed for an adverti ement or mall folder these positives may be enlarged for a brochure window card or po ter without repeating the steps of photographing through the process filters masking and creening Of cour e by en larging the screened positives the dot size (creen ruling) will become larger but the viewing dis tance for the larger image will be greater o the dot pattern will not be objectionable

Conversions Color plate prepared for letter press may be converted to off et by pulling proofs of the plates on cellophane or thin acetate film These positive proofs may be u ed directly in mak ing deep etch off et plate for same-size reproduc tion or they may be enlarged to obtain negatives for albumen type off et plates Other sy tems of conversion from letterpress to offset which can be used for same size reproduction are the Brightype and the d i Offset (direct image) method With these sy tems the entire color form would be con verted type as well as halftones The Brightype method treats the form with a thin black lacquer after which the printing surface is poli hed with an era er The form is put on the bed of the pecial vertical copying camera and photographed to obtain a film for offset platemaking The d i Off et system pulls a proof of the letterpress form directly onto a special paper backed aluminum foil plate which after a light treatment is ready for the off set press

Flat color work The mo t obvious method of put ting color into printing is that of printing one or two headlines or display line in another color To be more effective art work in the form of ketche borders or backgrounds may be printed in one or more colors in addition to the black u ually u ed for the main body of the text Such color termed flat colors have no variation in tone (as in proce work) but appear simply as an even film of ink on the paper A separate form or plate i prepared for each color with the various impre sions printed in register for the completed design Very often the break for color is made with tran parent overlay placed over the original with the required areas drawn on each o erlay The Benday method i u ed to break up the flat colors into patterns to give the impression of color tones A flat tint plate i ometimes printed under a normal black and white half tone to add color where the expen e of more elaborate handling is to be a oided

Posterizing A eldom u ed but ery plea ing pre entation of a ubject in flat c lors i that known as posterizing Here the black and white photograph is copied in three (ometime f ur) steps on eparate pieces of high contra t film Ex posures are regulated o the different tone of the original are interpreted a line negati e th high contrast film pre ent ind idual tones from appear ing tending to blend i termediate gradation into one tone for each expo ure In u ng three tep a short expo ure shows up onl the highlight in the

first egati e a long xpo u e pi ks up all t ne except deep h d w for the se ond neg ti e a d a med um e posure rep od ces th middle ange of t e nth th d egat e When p ti plates f h neg ti e re pr nted in r g ster u i g different t es of ink, a po te like rep odu tion i the re ult D tk med m nd l ht tone of th ame color p ted n lightly t t d pape fi ds g ne al pr f re e b t harmon zi g col r may al o be u ed

Split fountain A fa ly ommon pr ct ce in om m rcal pri t ng pl nt t g t ar ety f c lor i t pri ted j ece i the u e of a pl t f u tan Th k f t of the pri t ng p es i divid d int se eral mpartment wh ch p rm ts two or m e c l s t b appl ed t th pap r with o e p th gh th p ss As an xampl a two-color job may be run with ed n ne half of th p per and bl ck o the tl half By t n g the heet o nd fo a ond imp es n the j b n be c m plet d w th one half the u ual total number of im p es Th s method a n t b u ed nd crimi n t ly the j b mu t be plan ed ahe d f time t t k d t ge of thi tr ck f th tr de

Fluorescence process Ea tma K dak int o- d ed th method f prep ing wate ol ketche d the r be jue t r p od t on i 1941 It i milar t the fl o ogr ph c p ep ti n of wa h d f highl ght product o s n black and h t Spe l p gment furn l ed n k t f the ri t h eeds paint a he normally ld Th fi b d w rk w ll fl o esce or glow d ltra let l ght m king po s bl c lor ation with l ttle o orrect R prod ct on f ll w egul fo c l pro e r t nes but sp l filters re ed Th opyb d is ls u ded w th a peci l hood t all w control f l ght ng th wh te or ult let m xtu e of both ed Det l d instru t n the p es a av l ble f m Ea tr an

Variety of modern color printing Col has c me to be m h accept d by the Am can pub- li that ery l ttle print ng i pr d ed w tho t f n o e w y nother The d ly newsp per t d t n lly bla k nd white med m i b g n n g to col r At the m ment o ly an o l ad rt em nt ppe i lo but a few new pape s prese tly t lk of ROP (r n f the p per) ol n w pape w ll pr b bly oon j n m g zi i ffe i g col r t th i d erti Mod rn maga i s h ve l h lfto nea ly e ry page l r ph t graphy wa fi t used to l l i i a t ry th Am ric M ga i e in 1935 T xtbook n th c d m e t nge are p d mi ntly free of l r a ar els h wev l r i used f th ja k ts n ma y f th m Ch ldren bo k d gr de h l books re fill d w th color ers g t mak th m m re att cti e

Th a r g p me fa to f ce w th lo f t g in a hu dred f rms wh n h te t days d g i hardwa e t re o s perma ket The w l l r n me h nd ng i so mp rta t th t y t tud e ha be n m d of it b l t i m l i m Bes des l r s eff t on vi b l ty it sho ld al o con ey n mpre on of the cha act r t cs of the contents of th pa kage to th ewer I thi onnect col r p inting be come furthe involved i the te hn calit es of get t ng nk on many surfaces ther th n pape C llo- phane f l w x d pape a d plast cs pre ent problems of b o ption drying lu ter and f d ng Neve th le c l r printing in the field of fl xible p ckag ng nd foldi g bo es i a majo egm nt of the graph a ts i d try

M t l dec rat ng t pri ting also h s its p blems with olor p int ng M t f this wo k is d e by lithography using pre es which take a sheet of m tal straight through between blanket nd impre i n cyli der w thout b nding a ound the impr ssi n cyli der as s d n with pape F r proc s ol rs a white op que ba kg ound is first pri ted and baked the metal in tho a eas where th pr e c l s re to appea

There are m y oth sp ialty h es deal ng n ome indi id al w y with c lor print g Prod ucts n add t on to tho e touched up n he e in l d calend rs gre ting card labels heet musi de alcom nia pictor al po t ca d p t m p d fi e art ep du tion S e PRINTING PRESS

[K R B]

Printing plate

A block r heet f m tal wood plast or ther m te i l whi h ar e on ts f e a ep oduct on f d ig d win ph togr ph o ther rt wo k a d whi h, when placed on print ng p e s and inked tra fers the reprod tion t paper cloth met l or any the surfa capable of e ing t In pl tes mad f r l tterpr pr nt ng the r pro d ction o print g image s n relief In pl no- graph c pr nt g su l as l thogr phy the p i t g im g is n th s rf e of the plate on a l el with the n npr ting portion I int gl print ng (f r e mpl r t gravu) the p ting im g i incised o tched below the plate f ce

Plate f r pla og apl c a d taglio printing a e n id red epa t ly b low u der th pect e head gs

Wood engravings The l e t form of p inti g plate w th wood gravi g wh h b l e d t ha r gin t d in Ch na a d t h e b en u ed n b th Ch n and Jap n a ea ly a the e ghth centu y A D I Eu op it appea first in the block books f the e ly fifteenth ce t ry pr o t th i v nt of p int ng f om mo able typ a d po bly r l e th n 1400 The print f St Ch i toph rry g the infa t Cl st ac o s th w ll n tr m p bably th mo t famous of bl k p nt dat d 1423 J hanne G tenbe g d d t m ke f w od gra i g hi pag s b ng pri ted f om type and embell hed by ha d b i wo d e gra d n tials and d atio s pp b k pr nt d by h s su c s P S h ff a d th re r wood-engra ed l l st at n n bo ks of the late fift e th cent ry

I Ame i a wood e g g or woodc ts we w dely empl yed f b d magazin ll tr t n a d f mm r l w k a w ll up t th tim f

the introduction of the photomechanical halftone in the early 1880s It was from the cutting done in the making of a wood engraving that the term cut came to be applied to photoengravings generally The industry prefers use of the terms halftone or line engraving With the advent of the halftone which made possible the direct reproduction of photographs and other tonal copy the use of woodcuts rapidly declined and the process survives today mainly as a fine arts medium Besides wood (usually in the form of end grain boxwood) artists and art students make use of linoleum hard rubber and other workable materials which when mounted on blocks of the right height can be printed on a press along with standard type

In making a wood engraving the artist first either draws his design on the face of the block or transfers it to the wood by rubbing from a drawing previously made on paper Then with tools known as gravers or burins that resemble small gouges or chisels (a V pointed graver is used for incising fine lines) he cuts away those parts of the block that are not to print leaving the lines or areas of his design in relief Shaded effects are obtained by incising fine lines either in parallel or crossing each other as in cross hatching If the print is to be in more than one color a separate block is cut for each color The blocks are then printed successively and in register one with another

Substantially this same process has been used for centuries in the making of Japanese prints the effect of the colors being often enhanced by skillful manipulation of the inks and overlapping of tints

Steel and copperplate engraving Another type of engraving that is made by hand is the steel or copperplate engraving which in its original form dates back at least to the fifteenth century This is an intaglio plate with the lines of the design cut into the face of the metal In printing the plate is inked and the surface wiped leaving the ink only in the incised lines from which it is transferred to paper by combined pressure and suction The ink thus transferred when dry produces the raised effect seen in engraved stationery and formal announcements—an effect extensively imitated by the process known as thermography

Line engravings These the direct descendants of wood engravings are used in reproducing pen and ink drawings scratchboard and pebbleboard designs and similar material in which the lines or areas of the copy are in black on (usually) a white surface There are no intermediate grays in line copy as there are for example in a photograph The copy is placed on a copyboard in front of the engraver camera the distance between camera and copy is adjusted to bring the image to the specified size and an exposure is made On the developed negative the black lines or areas of the copy are white and transparent the whites of the copy both within and around the drawing are black and opaque

In the usual platemaking procedure the emulsion of the negative is stripped from the backing and squeegeed down right side up on a plate of glass (glass flat) along with other line negative The flat is then placed in contact negative side down with a metal plate the surface of which has previously been coated with an emulsion sensitive to actinic (ultraviolet) light Zinc usually in sheets of 16 gage thickness is the metal used for most line engravings copper also 16 gage is used for engravings containing fine detail or intended for long runs Magnesium has found increasing use in line work

Flat and plate are next put into a photographic printing frame and exposed to a powerful light This light passing through the white (transparent) lines of the negative tans the emulsion underneath rendering it insoluble in water where the face of the plate is shielded by the black (opaque) portions of the negative the emulsion is not affected and remains soluble The negative thus serves as a stencil admitting light only to what will eventually be the printing portions of the plate

After exposure the face of the plate is rolled with a grease ink or the plate is dipped in dye and washed under running water The ink or dye adheres to the parts that have been acted upon by the light but is washed away along with the dissolving emulsion from the unaffected portion thus bringing out the printing image which can now be inspected and at the same time leaving exposed those parts of the metal which are later to be etched away If necessary the image is treated with topping powder to make it acid resistant

In the etching process the plate is given as many exposures to the acid (bites) as may be necessary to bring the nonprinting parts down to the proper depth (0 025–0 040 in for newspaper plates) Nitric acid is the usual mordant if the metal is zinc iron perchloride if it is copper Open spaces between or around the lines in relief are deepened by routing and any dead metal is removed in the same way

In the final stage the plate is cut up into smaller plates corresponding to the several negatives and the separate plates after proofing are delivered either in that form to be used on patent bases or mounted type high on wood or metal bases ready to be inserted in a type form and printed with the type

By using a photographic positive instead of a negative in making the plate or using a negative print as copy the blacks and whites of the copy may be reversed so that the lines of the copy come out white and the whites of the copy black This type of plate is known as a positive or reverse line plate Another type of reverse plate is obtained by turning or flopping the negative when it is placed on the glass flat thereby reversing the copy from left to right and producing a mirror image

Benday plates The Benday (or Ben Day) process takes its name from its inventor Benjamin Day an American artist who brought it out about 1880 Essentially it is a method by which shadings or flat tone effects in the form of line dot grain stipple or other patterns can be applied mechanically to a

part o parts f a h rep duct Alth h it h bee l gel s pplanted by ther m th ds which m y be appli d by a t ts t p odu e sim l r effect the B nd y m th d i still d for rt ons n both black a d whit and l r and f r wo k h m p a d d agr m in wh ch secti area to be g en diff ent sh d ngs Th patterns f h h me 200 in ll are a l ble a in relief th face of B day scre — rect gl f hard d gelatin ra ng in si e f m 6 by 8 to 16 by 20 n

Th had r t ts m y be appl ed t the copy tself i g t p t of the c py (the lat t f e er e effects) to the pl t the la t m d being the te h iq e most comm ly used F this the opy (ally tl d w g) i phot printed the metal d the pa ts not t r ted the h d g a e pai t d n (t pp d o t) th g mb g a y ll w h cous sub t ce wh ch hen dry sol ble in wat r The p tte is ap plied by king the Be day en s l ted with gre e i k and p nti g t the face f th plate in l di g both gamb ged a d gamb ged por n s Th plate then wash d d ss l g the gam bog which n away w th it th p t d lines o d ts d lea e th pattern nly on th se a e s he e t i wa t d— r a that ha e b en i dicated o the c py o on a erlay by the tist The d ts r li of the p tte n are th n treated with topp g po de (acid e i t t) nd th plat is etched i the way s a l e plate

Of th meth d mploy d by rtist t p oduce B day effect the m st w dely used a the board h Craft t (impreg ated ith r two i t bl pattern) and sh d g she t (a te h q c ed by B F Hut hi on nd de el p d c m m rc ally by A B Bou ges) I the fir t se th art t makes hi draw g n lin the f ce of th bo d, th n p i ts the a ea to be shad d with liquid devel per wh h b i gs o t the patter n bl k With d ubl to e B a ds which rry the equ le t f l ght nd d k Be day p tter d fer nt de el per used f r ea h p tter P t t m n t be bl tted afte th y a b ught ut Th r ult i l e d w n mplet w th Be d y t t had g F sh o illu t atio s nd d w ing sh ng det l f m ch n y a m g th bj ct p od c d by thi m thod

The h d g heets a e t a sp e t sheets h h B day p ttern h e be pr t d When a a a t l e sh ded th art t ut n t fit from th d d he t d ppl es it e the a so th t t be me t ff t n t g al pa t f th copy (F g 1) Highl ght ff ts may b r d c d by sc p g ff th d i l r g a mp g th p tt rn w th k f Sh d g h ts e l m d th the p ttern p t d p q wh te f l ght g (gr y ng d wn) bla k r s o h avy let er g or type

An d nt g f both th boa d nd th had ng heet techn q es i that the h d g ppl ed by the rt t and nt ly u d r h nt l Both ar two f t th th r gul Be d y p oce W th

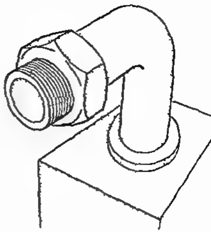


Fig 1 L d w g w th h d g h t l d to p d c h lft eff ct S p tt m d f m e wh l d wh t h w S l d bl k w l ked g l d w g (Am n M m f Ph t g a phy)

b th th fi l re It is l e copy wh h may be photog aphed d r tly witho t se f a halfton s reen d processed i the me w y as n di ry l plate

Altho gh t i n t a h d g p ces mention sh ll be made h n of th Tone Li p ce s nt oduc d by E stman K d k by wh ch l ne rep o ducti may be mad f om ph t graph A conti o s-t ne negat held i c nt ct with a tran parent p nt much in the m nner f b s el f photogr phy is th b sis of th s proces

Halftone plates The e are plate made fr m ph t g phs w sh drawing nd ther t work d e in nt uo tones th t r ge f m wh te through te med te gr y t black— distin guished f m th ll bl ck li a d are s f li n opy T rep d ce (r simul t) th e t es us i m de of the halft ne sc n which in its tand ard form s sts f two pl te f gl s h ruled (etch d) with fi e pa llel line a d m nted t geth f ce to f n that the l nes n ne cr s the lin n the th r t right gles Th l es are paque the spa e b twee them tra spa n t and l es and pac n the same w dth I th s een n erally u ed f bl ck a d white w k th li es ar t a les of 45 d 135 w th the s de

The s of a c is known by the n mb of the e li to th l i h F th g al un of l tt p s pr nt g th a g fr m 50 to 150 ele n of the s z t be d depend g p mar ly the m th s f fa e f th paper wh h th halft n to be pr nt d Th f n w p p work cr ns f 50–65 nd met me 8 l nes a e n mal w th 65 th i m t mm ly d f E gli h m ch ne fi sh pai 85–100 li f coat d p per 110 120 d 133 lin d for su p fi pap s nd n ial del x w rk 150 (Fig 2) In ge al w th n th ng the fin th cre n th m e f thf l th prod ct o w ll be t the g n l py S ee s f p to 400 l s a m d m tly f r p ial ed p rpo s

the introduction of the photomechanical halftone in the early 1880 It was from the cutting done in the making of a wood engraving that the term cut came to be applied to photoengravings generally The industry prefers use of the terms halftone or line engraving With the advent of the halftone which made possible the direct reproduction of photo graphs and other tonal copy the use of woodcuts rapidly declined and the process survives today mainly as a fine arts medium Besides wood (usually in the form of end grain boxwood) artists and art students make use of linoleum hard rubber and other workable materials which when mounted on blocks of the right height can be printed on a press along with standard type

In making a wood engraving the artist first either draws his design on the face of the block or trans fers it to the wood by rubbing from a drawing pre viously made on paper Then with tools known as gravers or burins that resemble small gouges or chisels (a V pointed graver is used for in ising fine lines) he cuts away those parts of the block that are not to print leaving the lines or areas of his design in relief Shaded effects are obtained by in cising fine lines either in parallel or crossing each other as in cross hatching If the print is to be in more than one color a separate block is cut for each color The blocks are then printed succe sively and in register one with another

Substantially this same proces ha been used for centuries in the making of Japanese prints the effect of the colors being often enhanced by skillful manipulation of the inks and overlapping of tints

Steel and copperplate engraving Another type of engraving that is made by hand is the teel or copperplate engraving which in its original form dates back at least to the fifteenth century This is an intaglio plate with the lines of the design cut into the face of the metal In printing the plate is inked and the surface wiped leaving the ink only in the inci ed lines from which it is transferred to paper by combined pressure and suction The ink thus transferred when dry produces the raised effect seen in engraved stationery and formal an nouncements—an effect extensively imitated by the process known as thermography

Line engravings These the direct descendants of wood engravings are used in reproducing p n and ink drawings cratchboard and pebbleboard de signs and similar material in which the lines or areas of the copy are in black on (usually) a white surface There are no intermediate grays in line copy as there are for example in a photograph The copy is placed on a copyboard in front of the engra er s camera the distance b tween camera and copy is adju ted to bring the image to the pecified ize and an exposure is made On the developed negati e the black lines or areas of the copy are white and transparent the whites of the copy both within and around the drawing are black and opaque

In the usual platemaking procedure the emulsion of the negati e is stripped from the backing and squeegeed down right ide up on a plate of gla s (glass flat) along with other line negatives The flat is then placed in contact negative side down with a metal plate the urface of which has previously been coated with an emul ion ensitive to actinic (ultraviolet) light Zinc usually in sheets of 16 gage thicknes is the metal u ed for mo t line engravings copper al o 16-gage is used for en gravings containing fine detail or intended for long runs Magnesium has found increasing u e in line work

Flat and plate are next put into a photographic printing frame and exposed to a powerful light Thus light pa ing through the white (tran parent) lines of the negative tans the emul ion underneath rendering it insoluble in water where the face of the plate is shielded by the black (opaque) portions of the negative the emulsion is not affected and re mains soluble The negative thus erves as a stencil admitting light only to what will eventually be the printing portions of the plate

After exposure the face of the plate i rolled with a grease ink or the plate is dipped in dye and washed under running water The ink or dye ad heres to the parts that have been acted upon by the light but is wa hed away along with the dis olving emul ion from the unaffected portion thus bring ing out the printing image which can now be in spected and at the same time leaving expo ed those parts of the metal which are later to be etched away If necessary the image is treated with topping pow der to make it acid resistant

In the etching process the plate is given as many exposures to the acid (bites) as may be nece sary to bring the nonprinting parts down to the proper depth (0 025–0 040 in for new paper plates) Nitric acid is the usual mordant if the metal is zinc iron perchloride if it is copper Open spaces between or around the lines in relief are deepened by routing and any dead metal is removed in the same way

In the final stage the plate is cut up into smaller plates corresponding to the several negati e and the separate plates after proofing are deli ered either in that form to be used on patent ba e or mounted type high on wood or metal ba e ready to be inserted in a type form and printed with the type

By using a photographic po itive instead of a negative in making the plate or using a negati e print as copy the bla ks and whites of the copy may be re ersed o that the lines of the copy me out white and the whites of the copy black This type of plate is known as a positi e or rever e line plate Another type of reverse plate i obtained by turning or flopping the negati e when it i pla ed on the glass flat thereby rever ing the copy fr m left t right and producing a mirr r image

Benday plates The Benday (or B n Day) proc ess takes its name from its in entor Benjamin Day an American arti t who brought it out ab it 1880 Es entially it is a method by which adings or flat tone effect in the f rm of l ne lot grain stipple or other patterns can be applied m hani ally t a

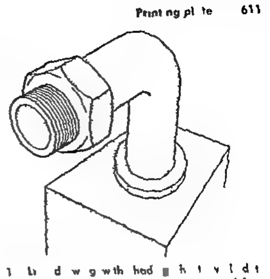
part t part of a l ne repr d tion Althou h it has bee l rg ly uppla t d by other meth d wh h may be ppl d l art ts t p odu m lar effects th Be d y meth d is st ll u d f r carto ns i both bla k nd wh t and c lor a d f r w k uch a map and d agram ir which sect ons r rea a t b g en d fferent sh din s The p tterns of h h som 200 n ll ar a lable a e el f n the f e l Benday creens—rectangles of ha d ened g lat n rangin i e fr m 6 by 8 to 16 by 20 n

The h d ng o t nt m y be pplied to th copy tself, t a g t e r po ti e of the opy (the lat t r lo reve se effect) r to the plate th l t n med be ng the te h iq e mo t omm nly u d F r thi the c py (ually n outl ne drawing) i ph t p t d on th met l a d th p rts not to re c i e th hading a e pai t d ve (st pped out) with gamb g a yell wish v ou ub t nce wh h wh n dry i oluble water The p ttern is ap pl ed by i k ng the B nday cree s lected with a grea e i k a d p i t ng it e the face f the pl te l ding both g mb ged and ngamb ged p r t. The pl te s th wa h d d s lv ng the gam bog whi h carries way w th it the ve p inted lines or d ts and lea the p tte n only n thos eas wh e it i w nted— rea that h e been in di ted on th copy o n ove lay by the art st Th d t r l e f the p tt rn a then t eated th t pp ng p wd r (ac d res st nt) d th plate is et hed the ame way a a li plat

Of th method empl yed by rt ts t p duc Be d y eff cts th m t w dely u ed are the b rds s h as Cr ftt t (mpregn ted with o tw ble p tt ns) nd sh d ng sheet (a techniq e co e ed by B F Hutch o and de loped m mer iall by A W B u ge) I the fi t ca e th rti t m k s h d w g I n the f ce of the bo d, the pa ts th s to b had d with a liq d d eloper h h b ng out the pattern n black. W th d bleto b a d which arry the eq l nt f l ght nd d k Be day p tt rn a different devel per i used f r e ch p tt n I t tern mu t be blott d fter they a e l ught out Th r li s a l dr w ng complete w th Bend y ti t e h d g F h n llustr ti d d aw g h g d ta l f ma h ry e am g th bject p oduc d by this meth d

The had g heets e t ansparent sh et n h h Be d y pattern have been p inted Wh n an a f he sh ded the a ti t a p t fit f m th d d h t a d appl t o the th t t bec m in ff ct n i tegral part of th copy (F g 1) H ghl ght effe t m y be p du d b sc p g ff th d t l m r g i mp i ng th p tt rn w th a k le S d g f ts are l e d w th the patt rn p ted in p q e wh t for l gh t g (sr y g d wn) bl ck a r h a y let ri g r type

In a f a t g f both th bo rd a d th h d ng sheet tech ques i that th shad ng is ppl ed by th rt i a d i e ti l nd h e nt l B th ar lso fast r than the reg l r Benday p oces With



F g 1 li d w g w th had h t v l d t d c halft e ff ct Sc p tt m d f m whe l d wh t how S l d bl k w k d o g al d w g (Am M m f Ph t g phy)

both the fi l ult is l copy whi l m y be photog aphed d r ctly with t u f a halftone sc een nd p oc ed i the same w y as n ord n ry l ne plate

Alth ugh t t a shading pro ess m tion ho ll be made here of th Tone-Line proce s i trod ed by Ea tman K dak by wh ch line repro-duction may b made from ph tog aphs A c nt n uou tone neg ti e held i conta t w th a t ns p ent pri t m h i the man of h s el ef ph t graph y the l a s of th s proce s.

Halftone plates These re pl t made f m photograph w h dr wi a d oth art work d e i co t uo to e that ng f om wh te th ugh ntermed at grays to bl k—as distin gui hed f m the all black l n s d are s f line py To ep odu (or m late) the e tones u e made of th halft s reen which n its tand d form co ts of tw pl te of glass e ch uled (or etched) w th fin parallel li s and c mented t g the fa t face s that the l ne on n o the li es on the the t ght a gl s The lines are op q e th spac s between th m transparent and l s and paces a the am w dth In th c en ge erally u d fo black nd wh t w k the l es t a l s of 45 nd 135 w th the s d s

The s f a s n s known by the numbe f the l t the l n ar in h Fo the neral r f lett p es p nt ng this ranges f m 50 t 1 0 s lect f the s z t be u ed d pendi p m ly on th m thn s f surface of the pape n wh ch th halfton t be n ed Th for w p pe work c en of 50-65 and s metime 85 l s are norm l w th 65 the t e r o t e mm nly ed for E gl h o m h ne fini h p pe s 85–100 lin fo c ated pape 110 120 a d 133 l s d f u perfin p p and p al d lu w rk 150 (Fig 2) In g neral within th rang the fine th reen the mo e f tf f l the retr d t or w ll b t the g l py S ns f up to 400 l n e mad mo tly for special d pu pose

the introduction of the photomechanical halftone in the early 1880 It was from the cutting done in the making of a wood engraving that the term cut came to be applied to photoengravings generally The industry prefers use of the terms halftone or line engraving With the advent of the halftone which made possible the direct reproduction of photo graphs and other tonal copy the use of woodcuts rapidly declined and the process survives today mainly as a fine arts medium Besides wood (usually in the form of end grain boxwood) artists and art students make use of linoleum hard rubber and other workable materials which when mounted on blocks of the right height can be printed on a press along with standard type

In making a wood engraving the artist first either draws his design on the face of the block or trans fers it to the wood by rubbing from a drawing pre viously made on paper Then with tools known as gravers or burins that resemble small gouges or chisels (a V pointed graver is used for incising fine lines) he cuts away those parts of the block that are not to print leaving the lines or areas of his *design in relief Shaded effect are obtained by in* cising fine lines either in parallel or crossing each other as in cross hatching If the print is to be in more than one color a separate block is cut for each color The blocks are then printed successively and in register one with another

Substantially this same process has been used for centuries in the making of Japanese prints the effect of the colors being often enhanced by skillful manipulation of the inks and overlapping of tints

Steel and copperplate engraving Another type of engraving that is made by hand is the steel or copperplate engraving which in its original form dates back at least to the fifteenth century This is *an intaglio plate with the lines of the design cut* into the face of the metal In printing the plate is inked and the surface wiped leaving the ink only in the incised lines from which it is transferred to paper by combined pressure and suction The ink *thus transferred when dry produces the raised* effect seen in engraved stationery and formal an nouncements—an effect extensively imitated by the process known as thermography

Line engravings These the direct descendants of wood engravings are used in reproducing pen and ink drawings scratchboard and pebbleboard de signs and similar material in which the lines or areas of the copy are in black on (usually) a white surface There are no intermediate grays in line copy as there are for example in a photograph The copy is placed on a copyboard in front of the engraver s camera the distance between camera and copy is adjusted to bring the image to the specified size and an exposure is made On the developed negative the black lines or areas of the copy are white and transparent the whites of the copy both within and around the drawing are black and opaque

In the usual platemaking procedure the emulsion of the negative is stripped from the backing and squeegeed down right side up on a plate of glass (glass flat) along with other line negative The flat is then placed in contact negative side down with a metal plate the surface of which has pre viously been coated with an emulsion sensitive to actinic (ultraviolet) light Zinc usually in sheets of 16 gage thickness is the metal used for most line engravings copper also 16 gage is used for en gravings containing fine detail or intended for long *runs Magnesium has found increasing use in line* work

Flat and plate are next put into a photographic printing frame and exposed to a powerful light This light passing through the white (transparent) lines of the negative tans the emulsion underneath rendering it insoluble in water where the face of the plate is shielded by the black (opaque) portions of the negative the emulsion is not affected and re mains soluble The negative thus serves as a stencil admitting light only to what will eventually be the printing portions of the plate

After exposure the face of the plate is rolled with a grease ink or the plate is dipped in dye and *washed under running water The ink or dye ad* heres to the parts that have been acted upon by the light but is washed away along with the dissolving emulsion from the unaffected portion thus bring ing out the printing image which can now be in spected and at the same time leaving exposed those parts of the metal which are later to be etched away If necessary the image is treated with topping pow der to make it acid resistant

In the etching process the plate is given as many exposures to the acid (bites) as may be necessary to bring the nonprinting parts down to the proper depth (0 025–0 040 in for newspaper plates) Nitric acid is the usual mordant if the metal is zinc iron perchloride if it is copper Open spaces between or around the lines in relief are deepened by routing and any dead metal is removed in the same way

In the final stage the plate is cut up into smaller plates corresponding to the several negative and *the separate plate after proofing are delivered* either in that form to be used on patent base or mounted type high on wood or metal bases ready to be inserted in a type form and printed with the type

By using a photographic positive instead of a negative in making the plate or using a negative print as copy the blacks and whites of the copy may be reversed so that the lines of the copy come out white and the whites of the copy black This type of plate is known as a positive or reverse line plate Another type of reverse plate is obtained by turning or flopping the negative when it is placed on the glass flat thereby reversing the copy from left to right and producing a mirror image

Benday plates The Benday (or Ben Day) proc ess takes its name from its inventor Benjamin Day an American artist who brought it out about 1880 Essentially it is a method by which shading or flat tone effects in the form of line dot grain stipple or other pattern can be applied mechanically to a

tal) h g d fo ea h lor This s d n so th t th d ts f th lo col r when pr ted will tend to be l g d o a ther ot on top of ne an ther thereby o d m e o patt rn an l bl g the eye t bl nd th m to eco dary an l t rt ry ol s Where blue a d yell w dots f r n t n e fall de by ide th eye ees them a a gree a d th m y b a blue gre a y llow green acc rd g t predomin ce f bl yell w d ts mil rly r ds d yellow bl d t pr duce a a d blue and ed t p odu v olets r p rples hile t rt y col uch as certa n b wns re p d d by the ble d of three and m time f r colo s Here ag in th eff t depends n opt cal ill on

Ph toe gr rs diff t which sc ee angles g e them t ff t e re lts b t age e on epa r t n of 30 b tw n c lor In what s prob bly th m t idely sed mb at on the sc een s set at 45 f r the bl ck (the gl at which the scree l es are l a t n t e bl) t 15 f the bl 75 f th r d nd 90 fo the y ll w h h be ng th l onspic col n t t ably ff ted by th h lf sep at on

E t e h nd fin h g d n m tly by reet h ing d (th n l mit) by b n h g is g rally ed d on t of olor plate t l ght o d ken p n of a pl te or plate a d to brin the col pr per b lan

Sever l method a e ilabl by wh ch l r pl te m y b mad w th ut th u of colo eg t n gat or l m y be f k d fr m bl ck a d h te opy but esults re seldom a d as he the egat es a e used

F ll l r pr d tio m y l o b ompl sh d by th th ee c l p cess wh ch th l r used ar yell w red (m g nt) nd blue da ke than th y n of f l pr It is cl med by ome ph toe gr er that t u c lo l e c n be obta d by th proc b t f ur col t er lly f ed p rtly fo th o th t the bla k a l bl f p int g typ the leg bility f h h is we ke ed by p nt g t c l r

Tw c l plates r f ma y kind a d c mbi t Th y may f ampl be mad from opy prep ed in th t colo s th t e to be rep o d d u h as pai ting do n t nes of g y d y d Whe e tw mpl me tary l n be used h s yell ra ge d a da k bl e pri gly wide a g f lor ff t m y be lta ed by ak lll l blend g f th c lor Mono-hrom t py h phot g ph f a ea ape be r p oduced two l r by m king two n gati es e ith co tr t a d deta l t nt bl k the the a fl t gr y n gati e t pply col l es a d pr nt m bl The l tter w ll be m f ith a 30 differ c c ee a gle S ch pl tes a e kn d t n or d gr ph T t bl ck t nt plat f metal o h rd rubber w th sold or ne ned s fa e b t w th de g e se pl t [type f l dr wi g re ed t d rp t type llu t ati n a ften wra m k n d ng

Electronic engravers Plates for letterp e print ng ca be produced by elect onic engra rs g ne ally f om to al copy and without the us of came as a d platemak n qu pm t U e of this de h s de eloped apidly nce the 1930s The m chin offered comm cially p du e halft es ryi g f m 50 to 200 line /in n pla tic zinc magnes m al m um opper r b ass acco d ng t the man factu r Mach f th type incl de the Fai ch ld Scanagraver an American prod ct the Kl hograph de el ped by R Hell of Kiel G rma y the Elorama pr d ced in Switze land and the H ssi g eng er in ent d by O Ha ing These mach s p oduce halft d ts sim lar t the t adit al e gra s dots The H s i g ma ch e c b u d to produ an unusual triang lar d t patt rn add tion t the usual d t st ucture (Fi 4)

On the Fa ch ld Sca agra e which was the p er Amer c n m chine the copy sually a glos y phot aph c p int b und r nd a small ho ont l yl nd r at the right f the ma h ne Mount d abo this an ele tric eye s ner On th left f the m hi the same haft a sim ilar yl nde round wh ch is b nd a thin sheet f plast c Abo this is tylus the t f which l ct ic lly e ted In te hous ng be tween the cyli de are the ntrol f th mach which go rn the d pth of th b te made by the tyl s

In operatio th cylind r ol e th s an n r icks p the bl k g ays and white of the py and co t them int l tr cal impul s f vary g te s ty wh h re tr nsmitted to the t l s Th tu n bit s nto the fa e of the pla t m l as the id b tes nto th p c b tween the d t a netal h lfto White a eas rec deep b t which l s mall d t bla k a ea a shallow b t which l v l g dot w th th gr y falling n b twee On the 65 l m ch ne wh ch

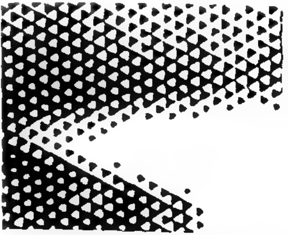


Fig 4 El t o lly g d h lft e d t Th highly e l g d d t l f h lft pl t hows b th d t t ct h d w a d h ght ght e d the p c l H g t g l d t (Am M m f Ph t g phy)

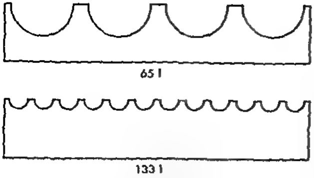


Fig 2 Cross section of photoengraved halftones showing the relief character of dots and the variations in spacing when different screen sizes are used (American Photoengravers Association)

The first mechanically ruled cross-line screen was produced by F E Ives in 1885 Prior to that however in 1880 the famous Shantytown halftone the first halftone printed in an American newspaper had appeared in the *New York Daily Graphic* This was made by S H Horgan using a one way screen Ruled and etched screens were introduced commercially in the middle 1880s by M and L Levy

In the making of a halftone the screen is placed in the camera directly in front of the film or photographic plate but not in contact with it The space between known as the screen distance varies with the nature of the copy but ranges generally from ⅛ to ¼ in Copy is placed on a copyboard in front of the camera and an exposure is made

Of the various explanations that have been made *of the effect of the screen the most acceptable* would seem to be a combination of the pinhole lens and light diffraction theories originally advanced by Ives and M Levy respectively Essentially and nontechnically the network of lines in the screen breaks up the image into dots of different sizes (Fig 3) White areas in the copy reflect the most light through lens and screen black areas the least gray areas in proportion to their lightness or darkness of tone When light from the white areas passes through the screen each of the tiny openings is believed to serve as a pinhole lens causing the rays to diffuse and to register on the negative as relatively large black dots In white areas such as highlights these dots will overlap producing on the negative the effect of very fine white dots on a black background Similarly areas that are black on the copy register on the negative as pinpoint black dots and the grays register as dots of varying intermediate size

In the platemaking stage these dots serve the same purpose as the opaque black portions of the negative in line engraving shielding the emulsion and keeping it soluble so that it dissolves when the plate is washed exposing *the metal for subsequent* etching The surface of a halftone plate thus consists of thousands of tiny dots of different sizes which the eye not being sufficiently microscopic to see them as dots blends into the darks mediums and lights of the original copy The halftone effect in other words is actually an optical illusion

Besides the regular network type screens numerous special screens are available These include the Kodak contact screen on film which is placed in contact with the negative and which has found more use in offset than in letterpress printing grain and wavy line screens and the double-textured Grafatone screen which combines two textures such as 65 with 85 line and 100 with 120

Halftone plates may be finished in several ways *Most widely used is the square (rectangular) halftone* common to all forms of printing Others are the silhouette or outline much used in magazine advertising in which the dots are removed from the background leaving the figure or product silhouetted against the white of the paper the highlight or *dropout, a favorite for fashion advertising in news*papers in which the dots are removed from the highlights by either manual or photographic methods and the vignette whole or partial in which one or more edges are feathered out or shaped into irregular background Where type and halftone or line and halftone are combined on the same plate the result is known as a combination plate

Color plates *Relief plates for color printing* are more fully considered elsewhere *(see* PRINTING IN COLOR) *For full color reproduction of paintings* color photographs and colored products such as fruits or fancy merchandise when shot direct the four color process is generally used In this by means of photographic filters color separation negatives are made for each of the three primary colors and for black From these in turn are made halftone plates which carry the yellow red and blue values with the black plate supplying definition and shading

In making these plates a rotatable circular screen is used by means of which the screen angle (angle of the lines of the screen with the horizon

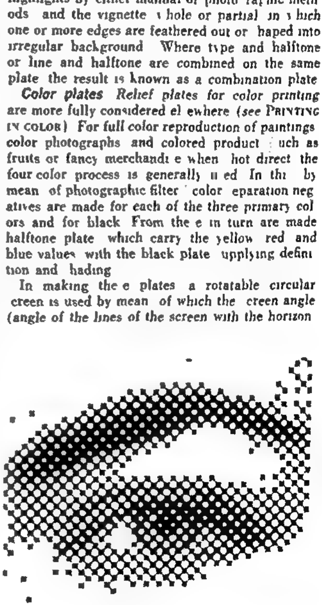


Fig 3 Greatly enlarged detail of photoengraved halftone plate showing dot formation (American Museum of Photography)

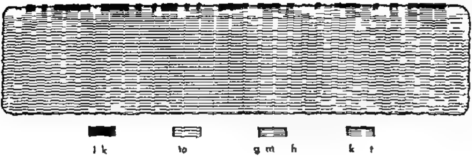


Fig 6 Lth t ob o pt

method inve t d m 1798 by A Senefelde and based on the m tual ntipatl y (epulsion) f gr ase a d wate It was originally carr ed out n l th t ne str t fied seco dary rock f nd m Sole h fen Ba a ia t the form of compact h moge eo slab n sting hiefly of cal ium arbonate

Lithog aphy Litho sto e is almo t perfe tly ad pted for l th graphy becau e l its por ty and n t ral tenden y to bsorb both gre s and ater An illustratio d awn with a greasy i k or cra on penetrates into the surf e of the tone as does a dil te sol tion of n t ic a d and gum ara (Fig 6)

Th d a ng or ill strat on f rms the a t l print g *image* on the ton th e d gum s lut on acts as *an etch* and converts th bare su fa es of the stone *int al ium nitrate* a chemical sur fa ing th t rem ins moderately d mp when m s-t ed th wat

Wh n the stone bearing the d awing moistened with *thin* aqueo i s lut on of gum a abic and the etted *s rfa e* immed ately rolled up with gr sy l tho pri t ng *ink* the ink adheres to the g ea y d aw g and s rep lled by the m i t (nonpr nting) the *stone* Thi p in iple stabl hed by Sen f lde i the b ic appl cat on of all l tho-graph pr t g cl d g off et

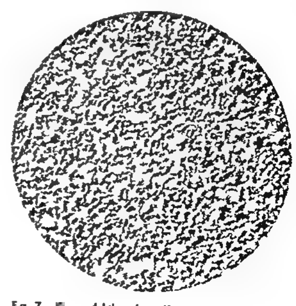
Lith *graphy fr* m to e is d e t pr edur b u e mpr n paper a e t ken fr m the ked images th to n The method eally i a h e art p oce s be a the qu lity of th epro-d rt depends up n th sk ll f th rt t The res lt po ble with the meth d we e h w in the so lled C r n and I e l th gr phs d p ctı g scenes f Am rican l f a d i t d ced n 1857 by N Curri r and J M I e

Despi t ut l ty a rt t med um l tho ha er cal d adv tage It e pe i heavy nd c mb r me a d r qu r s that pr t g be d n l w fl t bed pr es Se efelder r l ed th a d att mpt d 1800 t u e nc sheet as Eh pri t ng u fa es Al min m plates wer g ted 1891 by J Mull ly nd L. L. Bull ck b t ut l zat of metal plates fo l th print g d d n t see w de pra t cal appl t n until nt o-duct n l th ff et p es

O t p g Th p ess d gned in 1881 by F Ch mpen i and E. M r f wh t a tod y known as dry offset or letterpre transfer print ng was the r al b ginning of offset pr nting Litho graph c appl cati n of the off et pri ciple car be credited to I W Rub l who c n tructed 1904 a pr ss inc rporating th ee synch onously otati g cyl de s together with two re rvoirs for auto-mati lly feeding fountai soluti n and p inting ink to the litho pr splate attached to th fir t cyl nder The se ond cyl nder b a flexible rubber blanket to which th ink impr ssion w s tr ns ferred f retransfe to a sheet of paper tta hed to the third cyl nder

Litho metals ha e little porosity and som mea s mu t be prov ded f etain ng a film of mo ture on thei surface Th s is don by mechani ally gra n ng on side f the pl te with ab asi the grain h ving the dual functio of acting as a mois ture eservoir and provid g a tooth or ancho fo the litho imag on the gra ned *urface (F g 7)*

M t litho plate today are pr d ced by photo-lithography an rly method w the *albumen* p oce s, in e ted in 1855 by A L Poite in It re quir th g ained surface to be nsit zed with an aq e u luti n of b chromat d gg album n This oat ng become i soluble (t nned) through the a tion f act c light



Fg 7 d l th pl te X50

is made for newspaper use there are 65 such dots to each peripheral inch At the same time the scanner and stylus which are attached to grooved rollers and begin their action over the inner ends of their respective cylinders move gradually outward $\frac{1}{65}$ in at each revolution of the cylinders producing the equivalent of a plate made with a 65 line screen Plates up to 8 by 10 in in size can be turned out in 30 min or less Trimmed to the desired size with shears or a cutter they may be mounted type high on blocks to print with type or may be attached with two way adhesive to blank spaces left for them on the face of a stereotype plate

Line copy such as cartoons may also be run on the Scanagraver but will come off the machine with a background of fine black dots over the face of the plate similar to the dots of a Benday pattern

Closely related to the electronic engraving machines are the electronic scanners of Printing Developments Inc (American) and Hunter Penrose (British) In the Printing Developments scanner four color separation negatives without halftone screen are made simultaneously from flexible transparent color copy such as Anscochrome and Ektachrome films The Hunter Penrose equipment makes separation negatives one at a time and scans only flat or reflective copy

Duplicate plates These as the name implies are duplicates of original plates or type pages They are used for long runs as in the case of metropolitan newspapers and nationally circulated magazines for jobs where the originals must be preserved for future use for jobs to be run in multiple (printed from two or more identical plates or sets of plates) and when identical plates must be sent to several printers or publishers for use at the same time

The oldest form of duplicate plate is the stereotype used mostly by newspapers In this process the type page is locked firmly in a heavy metal frame called a chase and a thick sheet of papier mache forced down upon it by mechanical or hydraulic pressure so as to form a mold or mat (short for matrix) of the page From this a plate is cast in type metal which duplicates the printing surface of the original page If the plate is intended for use on a large rotary press it will be semicylindrical in shape if for use on a smaller tubular rotary press cylindrical and if intended to print with type on a flat bed press flat The stereotyping process is quick relatively inexpensive and especially suited for use by newspapers publishing several editions in which the front page and certain inside pages must be remade from issue to issue

When identical advertisements are to be run on the same date in a number of newspapers (as many as 400 sometimes in the case of national advertisers) they are usually sent to the papers in the form of stereotype mats From these flat casts are made which are inserted in the type page

A more durable plate used for large circulation magazines for much book work and for large edition advertising pieces is the electrotype For this the plate or page to be duplicated is molded under heavy pressure in wax tenaplate lead or vinylite and the mold suspended in a bath of copper sulfate where it is connected to the negative pole of an electric generator A bar usually of copper is also suspended in the solution and is connected with the positive pole of the generator When the current is turned on a thin coating of copper is deposited electrolytically on the face of the mold forming a shell which later is backed up with type metal to give the plate the strength and rigidity needed on the press Electrotypes are usually made flat and if intended for use on rotary presses are curved by mechanical pressure Flat electros to be mounted on patent bases are normally made 11 points (0 152 in) thick (Fig 5)

For extremely long runs requiring maximum plate durability electrotypes are faced with nickel or chromium Where the former is used the plates are sometimes mistakenly referred to as steel faced electrotypes Nickel besides being more durable is more resistant than copper to the chemicals found in certain printing inks

Electrotypes cost more and take longer to make than stereotypes but the process gives a more durable better quality plate suitable for use on smooth finish papers and capable of exact duplication of fine screen halftones and process color plates

Duplicate plates of vulcanized rubber and of plastic have found increasing use in recent years in book work and many forms of advertising and commercial printing Advantages include light weight ease of handling on the press and lower shipping cost A still more recent development the DuPont flexible photopolymer plastic plate introduced in 1959 has lightness of weight durability and speed of production to recommend it and gives promise of wide utility in the future [L.W.S.]

Planographic plates Printing plates of the planographic type are intended for lithography a

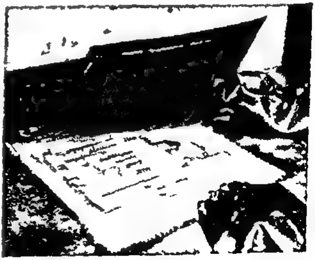


Fig 5 Removing electrotype shell from vinylite mold Shell will be backed up with metal to give it rigidity for printing (Rand McNally)

ing It t d tingu hed by du bility Collotype g t g i m ch l w th ff et lithography a d abo t 5000 i th max m m mb r of good im pre i n th t c n normally b e pe ted from coll t pe pl te

Intaglio plates These plat s d ffer from the plan gr phic var tv that the pr ti g image is m ed b l w th f e of a met l plate a d e p od ed by t o ma processe engraving a d tchin

Th t t ms a e often confu ed and used syn ymo ly b t eng ng properly efe s t m nual er ption f desig s on s faces w th the d of g a s or pe l cutt g implements The t rm etch g de ot in on f relief or intagl o des gns int met l f ce e ther by chem cal elect lyt act on and with ut us g e g i tool fa yk d Etch g a d e g avi g somet mes ar comb ed i t a ngle pr cedur such the exec ti n f o-called dryp int tchi g

I tagl gr ing i the lde t of all platemak ing m thod Copper w u d f r the p po in 149 b th G rma art st Albr ht D er C ppe pl t engra g a fa red m d um for ocial req tes cl d n p o l t tio e y w dd t i t d fi w k eq i g o ly a l mited n mbe f op es

A th f rm f i tagl g gra ng is th t pe f rmed te l pl te m thod or ginated i the l n ete nth t ry St el gr i g are more d bl than tho e x c ted o copper b t the result re n t a d l cat because of the h rde t e f te l Th m t imp ta t applic tio of nt gl e gr ng f b nk ot s d ecu i e d f the p d ti n f omm c al stati ery in the f rm f b n l tte heads

Copp r i n w p pul metal f r et hi g a d a fi t u d for th t p e i 1520 by the D t h rtist L a v Leyde It i p ef red fo et h ng p o edu e uch d ypoi t a d qu ti t ll rt t e g gs s h a mezz tint

Ph t t gl etch g d om d ma ual meth ds f g a g nd etch g It wa i t du ed in 1826 by J N pce, who the eby in ted phot eng a g and p nee ed the ba p n ple f photo-mech cs

Fig 10. Ph og vu g f m t

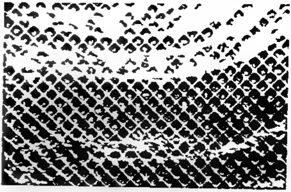


Fig 11 R t g p t g f

There ar two main meth ds f ph toi t gl o etch ng phot gra e a d r t gra ure With the first det l and t v l e e p rtrayed by a r in d t grain n the f e of coppe pl te (Fig 10) R tog ur mech n ed ve s n of ph t g avu e whi h it ha displ ced except for work f the h t q lity It til es a ruled ee fo t n l t n of t ne l s The screen di d s the i t gl et h n t ell (d pre sions) f un f rm s b t f ryi ng d pth a ord ng to th t n l s f the ig l (Fi 11)

B th phot g (1877) a d ot gr ure (1890) we e t e ted by e man the B hem an t t a d ph t me h n l e r her K Klic R tog e c n be d eith on flat c pper plat ppe urf ed cylinde a d mpre s s n be t ke fr m the et hed su faces o e th sheet f d r t ry (web fed) p e es The gre te t appli t n f th p s is i publica t n p i t d g me t l i g ery long p e s ru f mill on of mp e on

Th nly mm n de m at s betwe n photo gra re nd t a th t b th methods use li and co t t e p it a d nt il photo-re st n the f rm f bly n l b l zed t mag s p od d by e po of th p t n carb tis e (p gment p p) se s ti ed w th a c ti g of b h om t d g l t mp egn t d w th a red l r d p m t Et hi g f the mages on the pp f p f m d with i s f fe r c chl de l t f p s ly we ker st e gth (43–35 Ba m)

I ki g f ph t pl t s s f eq e tly pe f rmed by h d l r to a u e th urface of the tch d yl d fl d d with flu d nk f h gh l t l ty (dry g p w) d the e c s nk w p d f m the u f e f the cyli d w th a fl ible t l d t blad bef the nk d cyli der b ught nt ta t w th th web f pape t l g at h gh p ed th ugh a ta y gr re pr S PRI TING P INTING PRESS [J S M E]

B bl g phy H M Ca tw ight nd R M Kay *Rot g e* 19 6 L. Fl d a d J S Mertle *Mod n Phot g g* 1948 J S Me tle *Et l tio f R t g t* 1957 J S M rtl and G L. M n *Ph t m h cs d P t g* 1957 L. W Sipl y *A H lf C t y f Col* 1951 L. W S pley

Fig 8 Preparat o of ■ g t es for the mak ng of an offs t plate He e film of type ı be ng str pped into pos tion w th f lm of p ctu es (Ro d McN lly)

After exposure under a line or halftone negative the plate is covered with a thin film of greasy developing ink to promote visibility of the expo ed image and impart an ink attracting surface The image on the inked plate is developed with tap water which washes away the oluble (unexpo ed) portions of the albumen coating and lea es the inked image firmly attached to the grained surface of the metal

Of great importance to lithographers are photocomposing (tep and repeat) machines originated in 1906 by W C Huebner They fa ilitate accurate placement of images in any predetermined position on the surface of ensitized litho plate thus rendering po sible duplicate (repeat) prints which are tl ■ practical equivalent of electrotypes in a type form for letterpres printing

When many thou ands of impres ions are required deep etch plate are likely to l e u ed Produced in a number of way , uch plates entail u e of line and halftone positi es and differ from the albumen or surface variety in that the printing image is l rought into direct contact with the metal by a method of image re er al carried out chemically during the operation of platemaking

Still greater durability is achieved with bimetallic plate dating from experiments conducted in 1853 in France by H Garnier and A Salmon Bimetallic plates con i t of two different metals laminated together ■ an integral heet and ba ed on the supposition that me metal have greater affinity for litho ink

Certain plate of this category are trimetallic—made up of three different metal or all y t ch a zinc (or tainle s teel) copper and chromium They are more expen i e than the bimetallic ari ety A popular combination for the latter type ı copper and chromium The image areas are of copper becau ■ thi metal is readily rendered ink receptive whereas chromium ı con idered to be more water receptive and therefore forms the non printing areas

More economical (although le s durable) litho surfaces are pla tic and pre en itized plate They are simpler to make and were originally intended for mall off et pre e (office duplicators) typified by Multilith and Rotaprint machine

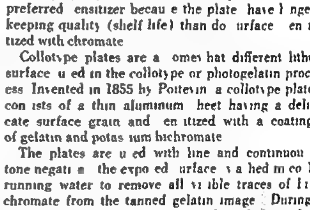
Plastic plate have mooth urface and are properly repre ented by articles having upport of resin impregnated paper or aponified heet of cellulo e esters Some of the urfaces are adapted for direct images (typewriting drawing) while others are of the photolitho type and en itized either with bichromate silver or ferric alts or diazo compound

Pre en itized plates have a en itizer incorporated in the surface coating by the manufacturer and are ready for expo ure by the u er A common form of such plate is a thin heet of aluminum coated with a diazo compound contained in a olution of polyvinyl alcohol Diazo compound are the preferred ensitizer becau e the plate have l nger keeping quality (shelf life) than do urface en itized with chromate

Collotype plates are a omewhat different litho surface u ed in the collotype or photogelatin process Invented in 1855 by Poitevin a collotype plate con ists of a thin aluminum heet having a delicate surface grain and en itized with a coating of gelatin and potas ium bichromate

The plates are u ed with line and continuou tone negati ■ the expo ed urface i a hed in co l running water to remove all vi ible traces of bichromate from the tanned gelatin image During i a hing a peculiar reticulation take place in the expo ed gelatin coating and erve a a grain or tone tran lation medium for reprodu ing the detail and gradation of the original sul ject (Fig 9)

Collotype is the mo t beautiful of all photolith methods the final result ■ an ink impre i n with the appearance f a photograph The plate ı kept moist with a glycerin water mixture during print



F g 9 Collotype g a fo m t o

ing It is ot d t gu hed by du abil ty Coll type p ting m h low r th n off t lithogr phy a d about 5000 i the max m m n mb r of go d im pres o th t c n rmally be expected fr m a coll t pe pl t

Intaglio plates The e pl tes d ff from the pl g aph c v riety in that th pr t g image is in sed below th rfa e of a met l pl te a d r prod ced f tw ma proce s engra i g and et hing

The t term a e often c nf d and u ed vn vm u ly but e r p op ly fers to m l i ipt o of de igns n u fa s with th d of gr ra r r pecı l c tt ng implem nt Th t rm et h g den te inc of r h f r nt gl de ons int metal rf e e the by hemical r electr lytic a ti and w th ut u ing ngra ing tool f any k d Et hi g and e graving met me e mbi ed nto a ingle proced re such as the execut n f o-call d drypo t et h gs

I ta l ng a g i the oldest f ll pl temak ng m thod Coppe wa u d f r the pu p e 149 by th German n t Albr ht D e Copper pl te e gra i g is fa or d m d m fo s i l req tes incl d g per nal t t o y w dd g t t t s a d fine w k equ i g nly a l m ted n mber of p

An th f rm of ntagl n engra i g i that pe f rmed teel pl te meth d n i ated n the es l teenth c ntury Steel ng ings ar m re d ble th th e ec ted o c pper b t th esult e n t d l cate becau of the ha de s f te l The mo t mp tar t appl at on f tagl engra g s fo ba k t and ti s and f r the pr d ction f mme al t tionery n the f m f bu s lette head

Coppe t n w p p lar met l f etch g a d t fi t used f r that p rpo n 1520 by the D h tt t L as an Leyden It i p fer d fo et h ng proc d es h dryp t and aqu tint ll art t ceng ng ch s mezz t t

Ph t t gl t h ng d med ma ual meth ds f g a g a d etch g It wa nt odu ed n 1826 b J N N epce wh th r by n ented ph to gra g a d p eered i the b pri e pl f ph to mechan cs

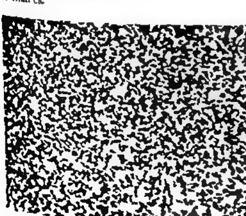


Fig 10 Photogravu e f m t

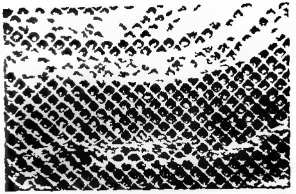


Fig 11 R t g p t g rf c

There are tw main m th d of phot nta lio etching phot gra re and r togra re. With the fi t d t il and t n alues are p rt ayed by a r sinou d t gra n o th rf c f c pp r plate (Fig 10) R tog a ure a m cha i ed ersion of ph t gra u which it h s d splaced except f r wo k of the h gh t qu l ty It ut lize a led scr en for t nslation of t ne l The c een d id s th ntagl o etch g nt cell (depr s on) f u if m z but of v ying depth cco ding to th t n lu of the ig nal (F 11)

B th ph tog e (1877) a d togra u e (1890) w e e ted by ne ma th Bohem n a tist and phot me h cal e e r h r K Kl c R tog a u e c n be do either o flat copper plat o c pper su fac d cyl nd s a d impres si ns an be tak n f m the etch d surfa es n e th r sheet fed r ta y (w b-fed) p s es The g eate t ppli at n of th pr ess in p blica t on p nting a d a t nments i l i g ery l ng pres ru of mill n f impre ons

The only mmo den m t betwe n photo-gr ure nd rot gra ure e th t both m th ds u e l ne a d cont uo s-tone p ti s d enta l photo-s st n th f rm f v bly ns lub l zed n g t v mages p odu ed by xp te f the po t es on ca b ti ue (p gme t p p r) tized with co ti of b chr m ted gelatin mp egnated w th a ed ol ed pigme t Et hing f the imag s n th coppe f es p f m d with i of fe ric chl ide solut on f pr g s ely we k tre gth (43–35 Baume)

Inking f ph tog a u plate s f eq ently pe f rm d by h d I rot gra u e th fa e of th etch d yl nd r s flooded with a fl id i k f high lat l ty (d y g p wer) a d the e ce s ink i w ped f m th s fa e of th cylinde with flex ble t el d t blad bef the k d cyl de i b ght t c ta t w th th w b of p p t l ng at h gh peed thro gh r ta y gr e p e s S PRINTING PRINTING PRESS [J S IE]

B bl g aphy H M Cartw ght nd R Ma K y *R t g u* 1956 L Fl d r a d J S M rtle *H d n Ph to g a g* 1948 J S M tl *E lu t f R tog e* 1957 J S Mertl a d G L M *Ph t m ch n d P ti g* 1957 L W S pley *A H lf C t y f Colo* 1951 L W S pley

The Photomechanical Halftone 1958 V Strauss *Lithographers Manual* 1958 B E Tory *Photo lithography* 1953

Printing press

Several kinds of printing presses are used in the three methods of reproduction most widely employed in the graphic arts namely relief (letterpress) printing planographic printing (as in lithography) and intaglio printing (steel and copperplate engraving and gravure)

Letterpress presses print from a relief surface *such as printers cast type (Fig 1a)*

In lithography (both stone lithography the original *hand method* and *offset lithography* the modern photographic method) the printing is from a planographic (even) surface using the principle of affinity of ink and grease for printing areas and the repellent qualities of water and grease for the nonprinting areas of the lithographic printing plate Stone lithography prints from the stone directly on the paper sheet On offset lithographic presses the printing is from a metal plate to a cylinder surfaced with a rubber blanket which offsets the impression to the sheet of paper tin or other substance to be printed In dry offset a relief etched printing plate 0 025 in deep is used to print the impression on the rubber blanket which offsets the impression to the sheet as in regular offset. The relief etched plate eliminates the need for water repellent facilities (hence the name dry offset) In direct lithography a thin metal plate is wrapped around a cylinder (the same as in offset and dry offset) and the impression is printed directly to the sheet instead of being offset to a rubber blanket and then to the paper Coarse grade work such as posters is generally produced by this process (Fig 1b)

In intaglio the printing is from ink deposited below the plate surface (Fig 1c) as in hand engraved or etched images in copperplate printing steel die stamping or photogravure (sheet printing production) and rotogravure (web printing production from rolls of paper stock)

Printing plates Printing plate requirements vary for printing presses in each of the three basic methods of printing Letterpresses print from original relief plates or forms consisting of type photoengravings or both in either line plates or halftones locked in a chase or from reproductive plates such as *stereotypes electrotypes rubber or plastic*

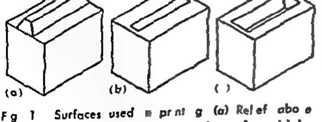


Fig 1 Surfaces used in printing (a) Relief above the surface (b) Planographic on the surface (c) Intaglio below the surface

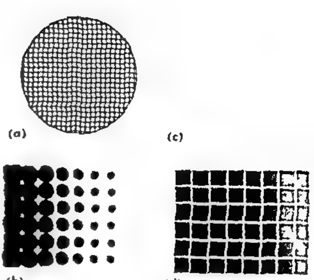


Fig 2 Printing plate screens (a) Halftone screen with black lines and white dots (b) Halftone screen with variable dot areas and equal ink film thickness (c) Rotogravure screen with white lines and black dots (d) Rotogravure screen with equal dot areas and variable ink film thickness

printing plates made from the original type and photoengraved plates The line plate photoengraving consists of variable line thicknesses and shapes for tonal valuations in an illustration The halftone photoengraving reproduces tonal pictures or continuous tone photographs through a system of graduated dots in relief (Fig 2a and b)

The halftone process produces halftone plates in which the gradation of tone in the photograph is reproduced by a system of graduated dots produced by a screen in which a network of fine lines that cross each other at right angles is placed between the camera lens and the negative The halftone printing plate surface consists of dots of various sizes uniformly placed and is capable of reproducing the highlights and shadows and all the gradations of tone in a continuous tone photograph The screen used to make the plate is designated by a number which indicates the number of lines (both ways) to 1 in Screen numbers vary but the most frequently used are 65 85 100 120 133 and 150 lines/in in both directions In a 65 line screen plate there are 65×65 or 4225 halftone dots/in² In a 150 line screen there are 150×150 or 22 500 dots/in In relief and lithographic printing the halftone dot uses the principle of variable dot areas and equal ink film thickness to reproduce a halftone illustration In letterpress printing this ink film thickness is approximately 0 0002 in In offset lithography the ink film thickness is approximately 0 0001 in

Photogravure and rotogravure halftones in monochrome (black sepia or other single color) are normally reproduced in dots of equal area and uniform placement but varying in the depth to which they are etched in the copper plate or cylinder Gradation of tonal values is controlled by the amount of ink deposited on the sheet from each

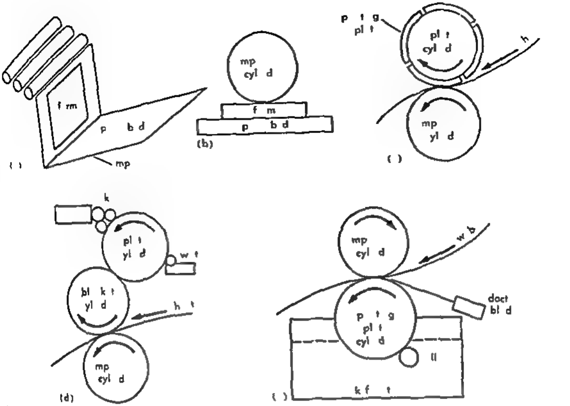


Fig 3 P t g p pl ( ) Pl t n (b) Fl t bed ( ) R t ry (d) Off et lthog ph ( ) Rotog w

ll dot, th s in turn be g go ned by the d pth of the ll or dot The p o e s thu use the princ pl of equal d t ar a and ble k film thi k ess. Th cree l e are ret d n th printi g pl te o cyl d th dots bei g et hed ut bet een them a d erve t s pport th d ct b d h h w pea th cyl nder el a and f e fr m nerfl s k l a g ink nly in the et hed d ts befo th impre o s made on the p p r (F g 2c a d d) Th screen g erally ed for m hrom wo k in gra ts k own th ro sl ne reen and co t f wh t line w th p q e p c be- tween th ces b g w de than the line For ex] k a p o e of comp at ly re e t de- l pment s n w quit widely d—the D ltgen Ha h I tagl Pro s—wh h make p s l t ry the ize a well the depth f the dx thu omb g th r bl a d ariable depth p n ple S e PRI TING PLATE

Th lk scr en proce f rep od ct on diff r f om th rel f pl gr ph d i tagl o method n th t th impr n pull d through a spe al lk screen (r w e scr en e mic print g) ene ng th mage t be p nted A h d ut (b gl h) r ph t graph (l ght e s t red base) mage pla ed a p pared reen w h th l ned-o t portio o t rry th nk th ough the sc ee nd s tr tch d r a f me The ink i pou ed into the f me at o e nd nd rried a os the reen with a r bber edged squeegee, h h p he the i k thr gh th and ont the heet which i n contact with the s reen dur g th pe ation The s lk creen p e s (ometim s c lled pa nt c een p ess) m l r to the mime graph p ces u ed n ffic n produ tio of letters whe e the me a e i typed o a typ writ r th ough a te c l and the me s ge is print d on a m me ph mach e b lt t queegee the ink th gh the te il stretched a o d th mach e cyl der (F g 3a b and)

Relief (letterpress) presses Relief t g pre es a e mo tly of th ee g al type (1) th plat pre in wh h b th the p nt ng f rm d the bed (pl ten) a e flat pl n rf s (2) the flat b d p e n wh h th pri ting form is fl t nd th mpr t p ll d ga n t a yl nd r (flat nd urved surf ce) and (3) the tary p es i wh h th print ng f m i a rved plate form and the mp e i i p ll d ag n t yl nd r (two e rved rfa e)

P e s m ke-r ady th op t n f l m t ng the mpe f tio s materi ls nd p e p epa t n f runn g the job th the printing pl te a d type w ll pre ent an even face to th p per Th ord f reasing difficulty in m k r ady rotary p flat bed d platen p Pl t n pres s the mo t d ffic lt t m ke re dy be u e th tw flat surf ce f the form a d th pl ten (r p bed) e t the p blem f eq al ng th mpre si n of th t f m er th e t re of the j b Fl t b d p es w th ne fl t a d o e curved f ce t p rt of the form

a continuous line the width of which is controlled by the size of the impression cylinder Rotary presses with two curved surfaces of the same size print the form in a continuous line thinner than that of the flat bed presses Rotary presses with large impression cylinders printing four and five colors from smaller plate cylinders have a wider pitch line (width of line printed at one time) than the smaller cylinders

Platen presses These presses also known as job presses because of the ease of hand feeding the sheet to the press have been used for many years in educational training activities The platen press is used for small size jobs that can be hand fed as well as for heavy card stock jobs that cannot be fed into a press which uses a curved cylinder to pull the impression

High speed platen presses have automatic mechanical feeders built into the press such feeders have increased the production of this type of press and put it in competition with the automatic jobbers (small cylinder presses) The addition of the automatic feeder has made it possible to produce heavy card stock jobs at relatively high speeds

Flat bed presses Large flat bed presses are also known as cylinder presses and the smaller sizes a automatic job cylinder presses The automatic job cylinder presses with high speed operation successfully compete with the slower speed large size cylinder presses On most job cylinder presses the flat bed is in a horizontal position to provide for sliding the form on the press for lock up and production Some job cylinder presses have their beds in a vertical position in the press These require locked up forms to be lifted into the upright position and snapped into place by a spring lock

Cylinder presses both large and small are generally of two revolution design one revolution to print the sheet and one revolution to deliver the sheet These presses have small size cylinder circumferences as compared with one revolution presses The one revolution large circumference cylinder presses print and deliver the sheets in one revolution of the cylinder

Automatic job cylinder presses have built in mechanical feeders and pile deliveries They are similar in feeding inking mechanism and delivery to the large cylinder presses They run smaller size sheets at greater press speeds They are now being built for one and two-color printing

Flat beds or large cylinder presses are built to produce one and two colors on one side of the sheet Automatic feeding and pile-sheet deliveries are used on these presses

Perfecting presses are built to print on both sides of the sheet from two forms each time the sheet passes through the press These presses are similar to the two-color flat bed cylinder presses but print both sides of the sheet instead of two colors on one side of the sheet They are used chiefly for book manufacturing printing where each sheet is completed in one pass through the press

Rotary presses Rotary presses print from curved plates against a cylinder or curved bed

Sheet fed rotary presses automatically feed and print sheets which are delivered in a pile These presses print from one to four and five colors at one time on one side of the sheet Some presses print all four or five plate cylinders against one large impression cylinder whereas other four and five-color rotary sheet fed presses print each plate cylinder against one individual impression cylinder thereby using one plate cylinder and one impression (packing) cylinder for each color

In web fed rotary presses the paper is fed to the press from a continuous paper roll or web Operation of these presses is similar to that of the sheet fed rotary presses in plate and packing cylinder operation They print multiple colors on one or both sides of the paper web When these presses are used in book work or for news paper production they deliver the job completely folded into signatures of 4 8 16 or 32 pages

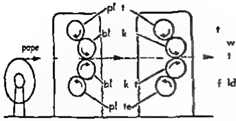
Heat set inks are used on high speed web fed rotary presses which produce at speeds of up to 1000 running ft/min At these speeds when four color are being printed it is necessary for the ink to be completely dry when the web passes through the folding delivery of the press Paper webs printed with heat set inks are passed through heated oven to dry the ink

Aniline presses The new name for aniline printing is flexography This method uses relief printing generally with rubber plates which are fastened to a cylinder and inked by a single inking roller The inking roller is supplied with aniline ink from two rollers in the ink fountain The amount of ink supplied to the form roller is controlled by the spacing of the roller in the ink fountain The presses generally are of the roll feed web press type and are run roll to roll rewinding the web They may also be run roll to sheet delivery The cut off operation is sometime adjustable to variable sizes The presses print multiple colors and the ink dries quickly which permits rewinding the web if desired

Special purpose presses Hard packing web presses are used for commercial production These presses are made ready in the same manner as the other presses used in the letterpress printing industry using a hard packing on the packing cylinder This gives a superior printed product with a clear sharp impression

News paper web presses use news print paper and soft blanket impression cylinder They do not use heat set inks or heated ovens in production News print paper with its absorbing qualities used with new ink dries satisfactorily at news paper production speed

Proof presses are used for pulling all kinds of proofs used in printing production such as galley proofs of type for first reading and page proofs for final reading Reproduction proofs for photographic reproduction of type for lithographic photogravure or other processes of printing are al



Fg 4 Offset p rf ct g p W b th ded f run g two l rs b th d f e w b

p lled n pr f p e es Pro f p e es are likewise ed t pull p oof ac t te heets f r pos t es deep- tch off t d rot gr e pl tem king operat

M lt gr ph p s p od ct rel ef (lette p es) method wh h u es rel ef ast sh rt type 0095 n h gh a d ff ent ted from typ high pri te typ f 0918 Th h rt typ i ld i t the gr o e f th Mult gr ph gment (cyl der t h ld the type) a d th cyl d s th n pl ced in th M lt gr ph m ch n whe th type ked and the imp take the he t a t s fed th gh the p b tw e the type a d th pl ten (Pl t n th name g e the r bb lle ag in t b h th mp e n pulled) Ele t otype nd rubbe pl te 0 095 h gh re al ed f r pr t g n th m ch e

Spec l bu lt l tte pre es ar d gn d t print pec lty prod ct h offc form l b l t gs d the l k Sp l plat s f typ rubb st eo- t pes ele t typ ar d thes pr Wh n rubb r pr ti g pl tes a b u ed xcl ely it po bl to b ld r ll f d web pr s th p ti g yl de of r ble c mf e e n t g f half h ll Two h lf h ll m ke mpl te pl te yl d r f ubb pl t th m pr p lled ga t a m th t l mp es- yl d Th mpr yl d p ti adj t bl t the r u d m t es f th pl t yl d ed t th p t g Th kt g m h n m l dj tal l t th pl t yl de es Th d ff t c c mfe pl te yl d rs p d l l heet es The pre t ff d ju tm t d l bl h t s es

Offset presses Th pl g ph m thod of p t g in l des p od t n ff et l th g ph p esse well n d e t l th gr ph p e e (F g 3d)

Sheet fed ff t p esse h e th m t l p t g pl t 00 t th k wh h th w k m g t dev l ped Th se pl tes m d f t l m n m ppe mb t f tw m t l f l met l pl t h h ed f r h gh q l t k P pe pl tes a se met m sed m ll p Th pl t f t ed d th pl t l w th l mps nd i d mp ed by p g d th t m h n m wh th p t g p t f th pl r t m t lt p g de th k g m h m wh th p g f the pl t ked Th pl t p th i ked im g on th f f th b

be blanket f tened t th blanket cyli de in the p s The p inted im ge is then offset or t ns ferred to the sheet as t p s es thr gh th p ess by pres ure pplied t the imp n cyl der in th press After it p nted the heet passed on t the del e y of the p ess Automat c feeder are d in the perati n f the heet fed ffset p ess

H e c l r ff et sheet fed p esses u ed in th in d t y ary sheet e fr m 10 by 14 to 52 by 76 in Two th a d four c lor p ses a e al ail ble

Off et perfe t g pr es print both side of the sh et at one time u ng the blanket to-blank t metl od f t an fer in the p inted mpr ion to the heet Th s method el mi ates the imp e n yl nder nd es the bla ket of th ppo te de of the sh et as the imp e on cyl nd r to t an fe the image t the heet Roll f d ff et web pre es metimes u e th s bla ket to-bl ket m thod of p nt g b th d s of the w b (Fig 4)

Roll feed ff t web p e s ar u d the same ma er lett pr web p e es S me pre p nt oll to- oll (rew d) others roll to heet o r ll to-f lder where complete folded signat re of a mult ple n mb of p g ar del e ed

M ltiple col off et p es es e f two de g s S me tr nsf eve l col rs f the pr ted imag t th rubb bl nk t a d the t n fe the m lt lo m ge t the h t n one imp es o Other t a fe the pri ted mage to the heet ne col at a time d n col r p e e (F g 5)

Dry off et p es s ope te n the sam m nne a w t ff t p The plat s d a e t hed 0 025 n r lief t tead f be g pla gr ph (on the rf e) The wat mech n m s m d back f m the pl t c tact nd made n p ati e d g th p t p at on Th k g me ha i m p at d the s me ma e s f w t ffset e ept th t the oller r qu mo deli ate et t g t p ev nt th r inki g th p i ti g part of th r l ef et hed pri ti g pl t The impres on

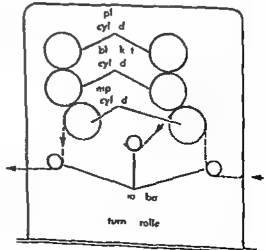


Fig 5 Offset typ p f p t g m lt pl l W b th ead d f ru g tw l d f w b

a continuous line the width of which is controlled by the size of the impression cylinder Rotary presses with two curved surfaces of the same size print the form in a continuous line thinner than that of the flat bed presses Rotary presses with large impression cylinders printing four and five colors from smaller plate cylinders have a wider pitch line (width of line printed at one time) than the smaller cylinders

Platen presses These presses also known as job presses because of the ease of hand feeding the sheets to the press have been used for many years in educational training activities The platen press is used for small size jobs that can be hand fed as well as for heavy card stock jobs that cannot be fed into a press which uses a curved cylinder to pull the impression

High speed platen presses have automatic mechanical feeders built into the press such feeders have increased the production of this type of press and put it in competition with the automatic jobbers (small cylinder presses) The addition of the automatic feeder has made it possible to produce heavy card stock jobs at relatively high speeds

Flat bed presses Large flat bed presses are also known as cylinder presses and the smaller sizes as automatic job cylinder presses The automatic job cylinder presses with high speed operation successfully compete with the slower speed large size cylinder presses On most job cylinder presses the flat bed is in a horizontal position to provide for sliding the form on the press for lock up and production Some job cylinder presses have their beds in a vertical position in the press These require locked up forms to be lifted into the upright position and snapped into place by a spring lock

Cylinder presses both large and small are generally of two revolution design one revolution to print the sheet and one revolution to deliver the sheet These presses have small size cylinder circumferences as compared with one revolution presses The one revolution large circumference cylinder presses print and deliver the sheets in one revolution of the cylinder

Automatic job cylinder presses have built in mechanical feeders and pile deliveries They are similar in feeding inking mechanism and delivery to the large cylinder presses They run smaller size sheets at greater press speeds They are now being built for one- and two-color printing

Flat beds or large cylinder presses are built to produce one and two colors on one side of the sheet Automatic feeding and pile sheet deliveries are used on these presses

Perfecting presses are built to print on both sides of the sheet from two forms each time the sheet passes through the press These presses are similar to the two color flat bed cylinder presses but print both sides of the sheet instead of two colors on one side of the sheet They are used chiefly for book manufacturing printing where each sheet is completed in one pass through the press

Rotary presses Rotary presses print from curved plates against a cylinder or curved bed

Sheet fed rotary presses automatically feed and print sheets which are delivered in a pile These presses print from one to four and five colors at one time on one side of the sheet Some presses print all four or five plate cylinders against one large impression cylinder whereas other four and five color rotary sheet fed presses print each plate cylinder against one individual impression cylinder thereby using one plate cylinder and one impression (packing) cylinder for each color

In web fed rotary presses the paper is fed to the press from a continuous paper roll or reel Operation of these presses is similar to that of the sheet fed rotary presses in plate and packing cylinder operations They print multiple colors on one or both sides of the paper web When these presses are used in book work or for newspaper production they deliver the job completely folded into signatures of 4 8 16 or 32 pages

Heat set inks are used on high speed web-fed rotary presses which produce at speeds of up to 1000 running ft/min At these speeds when four colors are being printed it is necessary for the ink to be completely dry when the web passes through the folding delivery of the press Paper webs printed with heat set inks are passed through heated oven to dry the ink

Aniline presses The new name for aniline printing is flexography This method uses relief printing generally with rubber plates which are fastened to a cylinder and inked by a single inking roller The inking roller is supplied with aniline ink from two rollers in the ink fountain The amount of ink supplied to the form roller is controlled by the spacing of the rollers in the ink fountain The presses generally are of the roll feed web press type and are run roll to roll rewinding the web They may also be run roll to sheet deliveries The cut off operation is sometimes adjustable to variable sizes The presses print multiple colors and the ink dries quickly which permits rewinding the web if desired

Special purpose presses Hard packing web presses are used for commercial production These presses are made ready in the same manner as the other presses used in the letterpress printing industry using a hard packing on the packing cylinder This gives a superior printed product with a clear sharp impression

Newspaper web presses use newsprint paper and soft blanket impression cylinders They do not use heat set inks or heated ovens in production Newsprint paper with its absorbing qualities used with news ink dries satisfactorily at newspaper production speed

Proof presses are used for pulling all kinds of proofs used in printing production such as galley proofs of type for first reading and page proofs for final reading Reproduction proofs for photographic reproduction of type for lithography, rotogravure or other processes of printing are also [illegible]

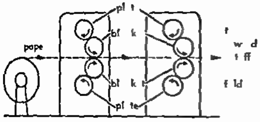


Fig 4 Off t p rf t g p W b th e d d f ru g tw l rs n both d f w b

p lled proof pre es Proof pr es are l kewi e used t p ll proof n ac tate she ts f r po iti s in deep- t h ff et nd t rav re pl temak ng op- e ti n

M ltigraph pre s p d cti a relief (letter pre) meth d wh h e el ef c t hort type 0 095 i high d ffer nt ted from type high p nte typ of 0 918 Th h rt typ i sl d nto the groo e f the Mult graph segment (cyl nd r t h ld th typ) a d the yl der i then pl ced in the M lt g ph mach wh re tl e type i ked d the impre s tak n the heet it is f d th gh the pre b twee th typ and the pl ten (Pl t n i the nam en th rubber r ller ga t h h th impres n is p lled) El tr types d rubber pl t 0 095 in h gh are l o u ed f pr t g n th m h

Sp ial bu lt l tterp es a de gned to pr nt pec alty produ ts su h ffice fo ms labels tags and th l ke Spe l pl tes of typ ubb r ste eo t pes r elect type a e u d on th e pre es Wh n rubl p i ti g pl te an be ed exclu ly t i po ible to b ld a r ll fed web p e s th a p t g c l der of vari ble rcumf r nc i t ng f h lf h ll Two h lf h ll m ke a mpl t pl t l d f r r bbe plate the m n i pulled ga t mo th teel mp e cyl d The imp t yl de p ti n adju t bl t th ari d am t es f th plate l d sed in the p t Th ki g me ha n m l adj table t th v plate yl der es Th d ff re t cir mf r plate cyl d rs p ovid ar able heet Th p e utoff d i im t d l a bl heet

Offset presses Th pl n graphi meth d of pri t ng l des pr d t ff t lith graph p ess a ll d e t l th g pl p es e (F g 3f)

Sheet fed ff t p h th n m tal p int ng pl t 0 02 i th k wh h th w rk im ge dev l ped Th pl tes m l f zinc lumi b met l plat wh h a u ed f b gh q al t k P pe pl tes re m t me u d m ll l nder th l mp a d damp ned b p ng nd th w t r mecha m wl e the p nt ng t m f th p l t a pt m t re It i k d l t i g f the pl t e inked The pl t the u f f th b-

be [redacted] nket fa tened t the blanket cyl der in the pr s The pr nted image s then offset or trans ferred t the sheet as it p ses th ough the pre by pre ure pplied t tl e imp es ion cyli der n the press After it i printed the heet s pas ed on t the deli ery f the pr ss A tomatic fe ders are sed i the op rat on of the sheet fed ff et press

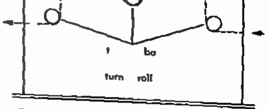
One color off et sheet fed pres es used n the in du t y v ry in h et size fr m 10 by 14 to 52 by 76 Tw th ee and fou lor pr ss s a e al o lable

Off et pe fe t ng p s es print b th ides f the heet at on time s ng the blank t to blanket m tl od of tra sferri the pr nted imp essi to th heet Thi method eliminates th impre i n cylinde and uses the blanket f the oppo ite ide f the heet as the impress on cylinde t transfer th *ima e to the sl eet Roll fed ff t web p e se sometime u thi bla ket to blanket meth l of* nting b th s des f the w b (F g 4)

R ll fe d ff et wet pres es are sed n the ame m n e as lette pr web pres s Some pre s p nt r ll to r ll (rew nd) oth rs r ll t heet r oll to f lde wh e mplete f lded s gnatu s of a mult ple number f pa es ar del ered

M lt ple c l r ffs t pr ses r of two design Some t a fer e al c l rs of the printed image to the ubl e bl nket a d then transf the m lti lo m g t the h et i one mp e ion Others tr fe the p nted im e to the sheet one olo at time a do o e col p e e (F g 5)

Dry ff et p e es op ate n the s me ma ner a wet ff et p es Th plat used a e et h d 0 025 i n rel f in tead f be g pla gr phic (on th u f e) The water m cha i m s m d ba k from the plate nta t nd made i oper ti dur g th p ti g operat The ki g me ha m ope t d the me ma ner s f wet offset exc pt that the olle q ire m e delicate set ting to p nt th r ink g the no p nt ng parts f th el ef t hed p ti g pl te Th imp e sion



Fg 5 Off t t type f p t g m lt pl c l W b th d d f tw l o d f w b

is pulled on the rubber blanket and transferred to the sheet in the same manner a in wet off et print ing The dry offset printing plate is really a relief printing plate although it is printed on an off et press

Direct lithographic pres es operate in much the ame manner as off et lithographic pre es except that the printing plate impres ion is printed di rectly on the heet in tead of off etting on the rub ber blanket and then being transferred to the sheet hence the name direct lithography

In direct lithography the printing plates read *from right to left* as in letterpress printing plates and type whereas offset lithographic printing plates read from left to right

Direct lithographic pres es can operate as sheet fed or roll fed web presses as de ired according to the demands of the product being printed

Intaglio process printing presses Copperplate printing presses come under two classifications hand and power driven The hand pov er press con sists of a flat bed and a curved impres ion urface much like tho e on a flat bed cylinder pre s Great *pressure is required for printing becau e the sheet* is forced down into the engraved plate to take out the ink When the plate to be printed has been inked it is wiped clean with soft chee ecloth and the printer s hand on which whiting (a fine pow der) has been applied The plate is then placed on the bed of the press the sheet to be printed is placed on the plate and the impres ion is taken by pulling the spokes attached to the shaft of the curved impression cylinder After the impression is pulled the press returns to the original position automatically and is ready for the next impre sion

The power driven copperplate printing pre s produces by hand feeding the sheet or card into the press for the impre ion This i taken from a print ing plate that has been automatically inked and wiped clean and free from superfluous ink ju t be fore the impression is taken on the sheet

The operation of steel plate engraving pres es is similar to the operation of a power driven cop perplate pre s The steel plate is u ed to withstand the tremendous impre sion pressure needed to take the ink out of the engra ing on the plate during the impres ion *cycle Steel plates are ometimes called* steel die the name gi en to the maller size plates which are about $\frac{1}{8}$–$\frac{1}{4}$ in thick The designs are hand cut rolled on or etched in the steel plate for bonds bank note and bu ine tationery The teel i gi en a hardening treatment to help it with tand the wear of production

The manner of printing a teel plate i the ame as that for th c pper plate The plate i automati cally inked and wiped clean with a paper wipe a roll of paper fed into the pre acro s the steel plate and rewound during the cleaning of the plate

The heets or cards to be printed are fed into and remo ed from the pre by hand Modern teel plate and die tamping pres e are roll fed with heet deli ery Letterhead o produced are cut from the roll after being printed and delivered in heet Drying of the heavy application of ink is done by infrared radiation A specially prepared ink i u ed

Steel die hand tamping pre e are mall crew activated swivel operated machines for u e on small dies such as monogram cre t and trade marks

Rotogravure presses Photogravure i any of the various proce es of producing print from an intaglio plate prepared by photographic method Rotogravure is a proce s of photogravure or in taglio printing in which the impre ion i obtained from etchings made on a copper cylinder which revolves in ink Photogravure is cla ified by th industry a printing from a heet of copper roto gravure as printing from a copper cylinder

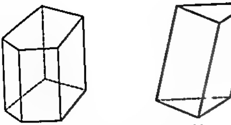
Photogravure pre es were originally built to print from flat heets of copper in the ame general manner as a flat bed letterpre s cylinder pre The inking mechani m and wiping mechani m were cumber ome Rotary photogravure pre es are built with a cylinder on which is fa tened the etched *copper printing plate with a doctor blade a thin* steel blade to wipe the uperfluous ink from the surface of the plate which revolves in a fountain of thin ink and with a rubber impre ion roller of suitable durometer to pull the ink out of the etched wells in the plate and onto the heet being printed The feeding and delivery parts of the pre s operate in a fa hion imilar to that of rotary pre es in off set and letterpre s printing

Rotogravure roll feed wel pre es print from metal coated or copper cylinder on which the image has been etched intaglio The cylinder re volve in ink fountains Thin ink is rolled into the etched cylinder in the fountain A teel doctor blade wipes off the superfluous ink which drops back into the fountain and the impre ion i taken against a rubber impre ion roller of proper durom eter to print the image harp and clear (Fig 3*e*)

The e pre es run multiple color four on each side of a wel if de ired The ink dries quickly enough to deliver the web into a folder if de ired The web may be deli ered into a sheeter t be cut into heets and deli ered from the pre *See* INK PRINTING [F W HO]

Prism

A polyhedron of which two face are congruent polygons in parallel plane and the other face are parallel gram The ba e *B* are the congruent polygon the lateral face are the parall lo gram the lateral edge are the edges not lying in the ba e and the perpen licular di tance be tween the ba es is the altitude *l* Section parallel to the ba e are congruent to the ba e A pri m i a right pri m if it lateral edges are perpendicular to the ba e an oblique pri m otherwi e A pri m i called a triangular pri m if it ba e are triangl a pentagonal pri m if it ba es are pentag n and a parallelepiped if it ba e are parallel gram



( ) (b)

P ( ) R ght p m (b) Obliq p m

Th l me f a y p m i q i l t the area of its ba e t mes it alt tude ($l = Bh$) *See* POLYHE DRON PRI MATOID A D PRISMOID [J.S.T.]

Prism optical

An opt l sy tem n ting f tw or m u ally pl f es f tran pare t a l d t an angle th h other Pr m are sed f r devi ting l ght S the am t f d i t on depe d n th r f t e i de f th prı m whi l ari th w l ngth pri m can l be u ed f r d pe s g l ght. *See* DISPER ION (RADIATION) REFRACTIO OF WAVES.

Reflecting prisms Pri m can be u ed in l u of m rr rs f r d at g l ght w th the add d ad tag that th reflect g surf are pr te ted g t c rro I th ca e th re i t l t int rnal r flect When the gles f inci d e a d emerg ce a e r the e no d per n Th er all d pers i l z r when the geometry f th p m i h that the d per i at the nte g rf i c mp ated by d per n the ppo te e at the em rgent rface Fo a d t led d f imp t t type f re fl cti g pri ms e MIRROR OPTICS

Dispersing prisms D pe g p ms dev t l ght of d ff ent wa el gths by d ffe t m unt nd th y an the efore be ed t p rate wh te l ght i t it m o h omat p t A p ll l beam of l ght nt i g the pr m l a e the p m a a p llel b am of l ght b t t d met may b ch ged The at of ts d am t aft r r fr ct o t at d m ter l ef re refract on can be c il re l as t l mag if ati n f the pri m

Th pri m magnif c ti f r a l un ll parall l t ll pri m e lge i alway q al t unity wl erea in the me li al plan (n rmal t the edg) a the ngl of in i l n i aried It i e q al to unity i thi pl ne nly if tl pri m i tra r ed at m im m levi tion If α i the pri m angl n the refra ti e ind n l δ th devi ti n it c n be sh wn that for minim im devi ti n

$$\sin (\delta + \alpha)/2 = n \sin \alpha/2$$

T i ere th di per n ever l pri m with tl ir r fr ti g edg p rall l can be u ed Th Rayleigh pri m h wn i Fig 1 i a ampl of uch a ystem By u ing pri m m d f a ma t ri l ch a fl nt gl that ha high d pe i n and add g e r m re pr m made f a m t rial ha ing a l w d per i u l a er wn gl s (see Fig 1*b*) tl e d iat n e be n tralized with neutral zi g the d pe n t gi a d rect i

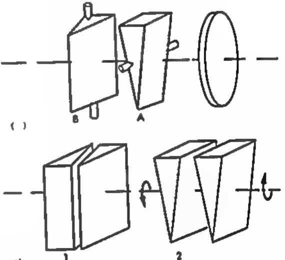
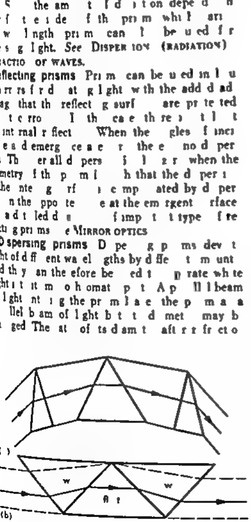


Fig 2 ( ) P of p m d fo ryl g m g if o- t i m y t m (b) P of p m (R l y p i m y t m) d fo ry g d t o

p i m y t m The ar a gem t h wn i F'g 1*b* i kn wn th Ami pri m y t m By ing a simil g m t but adj ti g the angl that th di p k t t th de i ti n i u trali ed i p bl t m k p i m y t m that i ach m t m ll p rt of th p ctr m l k h mati l *S* LE S OPTICAL.

A h m t m n f nt of a pt cal ys tem w th t fra t g dg rmal t the m i dio- l pla e an be ed t h ge th m gnifi ation f the pti al y t m th t plane Thi am unt ca be ri d by r tati g p m A i F g 2*a* bout x s rm l t the m d n l pl A c d m t c p m with t dge p llel t th me d onal pla be ed t dju t the g tt l m g fi t f the opt l y t m Ther f re n arra g me t f tw ch pr m with th ir m t



Fg 1 So typ f d pe g p m ( ) R yl gh syst m (b) Am i d t i y t m t g f fl t-gl p m d tw w -gl p m

is pulled on the rubber blanket and transferred to the sheet in the same manner as in wet offset printing. *The dry offset printing plate* is really a relief printing plate although it is printed on an offset press.

Direct lithographic presses operate in much the same manner as offset lithographic presses except that the printing plate impression is printed directly on the sheet instead of offsetting on the rubber blanket and then being transferred to the sheet; hence the name direct lithography.

In direct lithography the printing plates read *from right to left* as in letterpress printing plates and type, whereas offset lithographic printing plates read from left to right.

Direct lithographic presses can operate as sheet fed or roll fed web presses as desired according to the demands of the product being printed.

Intaglio process printing presses Copperplate printing presses come under two classifications: hand and power driven. The hand power press consists of a flat bed and a curved impression surface much like those on a flat bed cylinder press. Great pressure is required for printing because the sheet is forced down into the engraved plate to take out the ink. When the plate to be printed has been inked, it is wiped clean with soft cheesecloth and the printer's hand on which whiting (a fine powder) has been applied. The plate is then placed on the bed of the press, the sheet to be printed is placed on the plate, and the impression is taken by pulling the spokes attached to the shaft of the curved impression cylinder. After the impression is pulled, the press returns to the original position automatically and is ready for the next impression.

The power driven copperplate printing press produces by hand feeding the sheet or card into the press for the impression. This is taken from a printing plate that has been automatically inked and wiped clean and free from superfluous ink just before the impression is taken on the sheet.

The operation of steel plate engraving presses is similar to the operation of a power driven copperplate press. *The steel plate is used to withstand* the tremendous impression pressure needed to take the ink out of the engraving on the plate during the impression cycle. Steel plates are sometimes called steel dies, the name given to the smaller size plates which are about ⅛–¼ in thick. The designs are hand cut, rolled on, or etched in the steel plate for bonds, *bank notes, and business stationery*. The steel is given a hardening treatment to help it withstand the wear of production.

The manner of printing a steel plate is the same as that for the copper plate. The plate is automatically inked and wiped clean with a paper wipe, a roll of paper fed into the press across the steel plate and rewound *during the cleaning of the plate*.

The sheets or cards to be printed are fed into and removed from the press by hand. Modern steel plate and die stamping presses are roll fed with sheet delivery. Letterheads so produced are cut from the roll after being printed and delivered in sheets. Drying of the heavy application of ink is done by infrared radiation. A specially prepared ink is used.

Steel die hand stamping presses are small screw activated *swivel operated machines for use on* small dies such as monograms, crests, and trademarks.

Rotogravure presses Photogravure is any of the various processes of producing prints from an intaglio plate prepared by photographic methods. Rotogravure is a process of photogravure or intaglio printing in which the impression is obtained from etchings made on a copper cylinder which revolves in ink. Photogravure is classified by the industry as printing from a sheet of copper, rotogravure as printing from a copper cylinder.

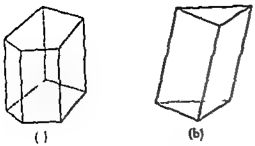
Photogravure presses were originally built to print from flat sheets of copper in the same general manner as a flat bed letterpress cylinder press. The inking mechanism and wiping mechanism were cumbersome. Rotary photogravure presses are built *with a cylinder on which is fastened the etched* copper printing plate with a doctor blade, a thin steel blade to wipe the superfluous ink from the surface of the plate which revolves in a fountain of thin ink, and with a rubber impression roller of suitable durometer to pull the ink out of the etched wells in the plate and onto the sheet being printed. *The feeding and delivery parts of the press operate* in a fashion similar to that of rotary presses in offset and letterpress printing.

Rotogravure roll feed web presses print from metal coated or copper cylinders on which the image has been etched intaglio. The cylinders revolve *in ink fountains. Thin ink is rolled into the etched cylinder in the fountain.* A steel doctor blade wipes off the superfluous ink, which drops back into the fountain and the impression is taken against a rubber impression roller of proper durometer to print the image sharp and clear (*Fig. 3e*).

These presses run multiple color, four on each side of a web if desired. The ink dries quickly *enough to deliver the web into a folder if desired.* The web may be delivered into a sheeter to be cut into sheets and delivered from the press. See INK PRINTING. [F. W. HO.]

Prism

A polyhedron of which two faces are congruent *polygons in parallel planes* and the other faces are parallelograms. The bases *B* are the congruent polygons, the lateral faces are the parallelograms, the lateral edges are the edges not lying in the bases, and the perpendicular distance between the bases is the altitude *l*. Sections parallel to the bases are congruent to the bases. A prism is a *right prism if its lateral edges are perpendicular* to the bases, an oblique prism otherwise. A prism is called a triangular prism if its bases are triangles, a pentagonal prism if its bases are pentagons, and *a parallelepiped if its bases are parallelograms*.



P ( ) R ght p m (b) Obliq p sm

Th l me of any p m s eq l t the ar a f its b se t mes its alt tud ($I = Bh$) See POLYHE DRO PRI SATOID A D PRISMOID [J S F]

Prism optical

An pt al y t m c ti g f tw more u ally pl rface f a tra p rent ol d at an a gle w th h oth r P m are used for de ati g light S ce the am nt f d i t d pe d n the refra t e dex of th p r m wh h a e w th a le gth, prism c n l b u ed f r d pe g l ght. Se DISPERSION (RADIATION) REFRACTION OF WAVES

Reflecting prisms P ms n be ed in l e f m rr s f r dev at ng l ght w th the added ad t g th t the reflecting urf es are pr tected g t e rr I this c e there s at l a t tern l refl t n Wh n the angl s f i d c nd m g re ze th e s no d p r n. Th o er ll d p to s al z ro whe th geometry of th p m s such that the d pe io at th e te i g rfa is c mpen t d by d per n s the ppos te a nse at the eme gent urf ce For a d t l d discus on of mp rt t typ s of re fl t g p m e MIRROR OPTICS

Dispersing prisms Di pe ng pr ms devi te l ght f d ffe e t w v length by differ nt am unt and they a theref e b u d t parate white light nt its m n hr mat parts A parallel beam f l ght ent ring the p m les e the p i m a p llel beam of l ght but its d ameter may b h ged Th r t o f t di met afte f ction

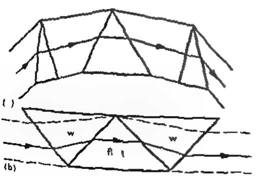


Fig 1 S m typ f d p g p m ( ) R yl gh p y t m (b) Am d f y t m t g f fl t-gl p m d tw c w-gl p m

to it d ameter lef re r fraction c n le c n i l red a the magnif cati n f tl e pr m

Tl e pri m mag ifcati n f r a l n ll parallel t the pri m edge s alw y eq al t un ty wl er a it ar e in tl m ridi n l plan (n rm l t the edg) a tl e angle f in id n s v ried It s equal t u ity in th s pl ne o ly if th p i m s trav r ed at minimum d s ti If α s th pri m ngle n th r fra ti ind x and δ tl deviati n it c be show tl at f r minimum deviati

$$\sin(\delta + \alpha)/2 = n \sin \alpha/2$$

T mer a e the d p r s n sev ral pri m with their refra ti g edg par ll l c n be s ed Tl e R yl gh p i m h wn in Fig 1a s an example f s ch a y tem By u i g a pri m mad f a ma teri l s ch a fli t gla tl at h a l igl ly per n a d dd g ne r m re pri m m d f mat rial ha ing a low d per n su h a crown gla (se Fig 1b) the d iat n an be ne tralized w th ut neutral zing the d persi n t g e a direct vi i n

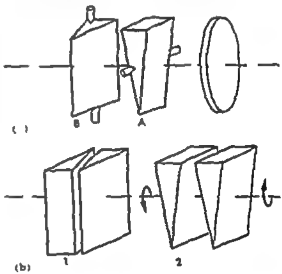


Fig 2 ( ) P f p i m s d fo varyi g m g f ca t si o m y tem (b) P i f p i m (R l y p ism y t m) u d f ry g d ot

p m y t m The a gement h wn i F g 1b is k own a tl Ami i p i m sy tem By u ing a m fa ng me t b t dj ti g the angle so th t th d per on but n t th d iat i e t l ed t i p sible t m ke p m sy t m th t a h matic e small p t of the pe trum l ke n h m tic le S LENS OPTICAL.

A a hr mat pri m in fr t of an optical sys tem w th t ef acti g edg n m l t tl e merid o n l pla e be us d t cha ge the magnifi at f the pt al system that pl e This am t a be ried by r t t g p i m A n Fig 2a ab t i norm l to th m d al pl e A s d hr m t pr m B with it edge p llel to th m d al pla e c n be u d t dj t the *gittal* m g ifi t f th opti al y t m The f e an rr g me t f tw s ch p ism w th th ir m t ns

linked together can be used to form a variable-focal length lens system called a zoom lens. See ZOOM LENS.

A thin prism is one whose angle is so small that the angle in radians is practically equal to the tangent. Such prisms are used in ophthalmology and their powers are usually expressed in prism diopters (*see* DIOPTER). The Risley prism system used for testing ocular convergence consists of two thin prisms mounted so that they can be rotated simultaneously in opposite directions, as shown in Fig. 2*b*. When they are in the orientation sketched at 1, their combined deviation is zero; when both have been rotated by 90° in opposite directions, as shown at 2, their combined deviation is a maximum; at intermediate positions their combined deviation lies between zero and the maximum, but the plane of deviation is constant. A similar pair of rotating wedges is used in certain types of rangefinder. *See* RANGEFINDER, OPTICAL. *See also* BINOCULARS; OPTICAL MATERIALS; OPTICS, GEOMETRICAL; PERISCOPE; RESOLVING POWER (OPTICS). [M.H.]

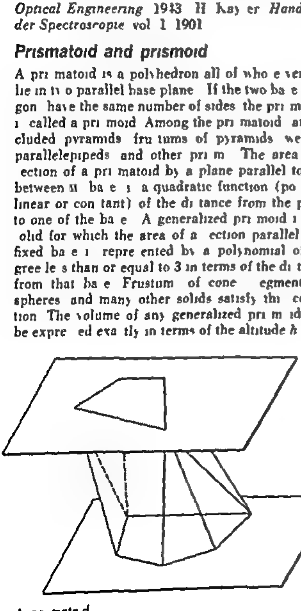
Bibliography: D. H. Jacobs, *Fundamentals of Optical Engineering*, 1943; H. Kayser, *Handbuch der Spectroscopie*, vol. 1, 1901.

Prismatoid and prismoid

A prismatoid is a polyhedron all of whose vertices lie in two parallel base planes. If the two base polygons have the same number of sides, the prismatoid is called a prismoid. Among the prismatoids are included pyramids, frustums of pyramids, wedges, parallelepipeds, and other prisms. The area of a section of a prismatoid by a plane parallel to and between its bases is a quadratic function (possibly linear or constant) of the distance from the plane to one of the bases. A generalized prismoid is any solid for which the area of a section parallel to a fixed base is represented by a polynomial of degree less than or equal to 3 in terms of the distance from that base. Frustums of cones, segments of spheres, and many other solids satisfy this condition. The volume of any generalized prismoid can be expressed exactly in terms of the altitude h and the areas L, M, and U of its lower base, midsection, and upper base by the important prismoidal volume formula

$$V = \frac{1}{6}h(L + 4M + U)$$

See PARALLELEPIPED; POLYHEDRON; PRISM; PYRAMID AND FRUSTUM. [J.S.F.]



A prismatoid

Privacy systems (scrambling)

Devices and methods for ensuring the privacy of overseas telephone conversations handled by radio links. Such privacy can be accomplished in a variety of ways; two are particularly widely used at circuit terminals.

The first method employs equipment for inverting speech to make overseas telephone conversations unintelligible to the casual listener. At the originating end, devices change the speech-conveying signal, making high frequencies low and low frequencies high, for example. At the distant end synchronized equipment restores the inverted speech to its original form for delivery to the listener.

A more complicated method employs filters to separate the transmitted speech signal into several narrow frequency bands. Each of these is then treated differently in a prearranged manner, the relative positions of individual portions of the signal being interchanged in the frequency spectrum by inversion and transposition. At the distant end associated equipment puts the full signal back together in proper shape so that the listener may receive intelligible speech. This method, particularly if such changes are automatically varied every few seconds, makes possible a radio transmission system that is very difficult to decipher. *See* FILTER, ELECTRIC; TELEPHONY. [C.C.DE.]

Probability

Although probability theory derives its notation and terminology from intuitive vague statements such as "John will probably come," it is as remote from it as the statement "John is forceful and energetic" is remote from mechanics. Probability theory constructs abstract models, mostly of a qualitative nature, and only experience can show whether these reasonably describe laws of nature or life. As always in mathematics, only logical relations and implications enter the theory, and the notion of probability is just as undefinable (and as intuitive) as are the notions of point, line, or mass. An actual assignment of numerical probabilities is frequently unnecessary or impossible. For example, telephone exchanges are based on a theoretical comparison of several possible systems; only the optimal ones are built and the others discarded. Thus a huge industry depends on theoretical models of exchanges which will never exist. A simple illustration of the nature of probability models is found in Lord Rutherford's experiment

E ampl (*a*) To mea u e radı act n inten ty Lo d Rutherford proceed d as f ll w Ol rv r A a d A_2 co nted c ntıllatı n a er en and observed espect ly N and N ı tıllat f these N ere mm n t both l rver To e tı m t the u kn w tr e umber N II therf r l as-sum d th t ea h cı tıllatı n h f xed pr bal ıl ues p and p t be b rved by A_1 and A d f h rm r th t th b ervatı n are ı d pend nt ın the e th t cı tıllatı ol rved b A_1 ha still prob bil t p t b ob rved l y A In reality th l kel hood f ob r a sc ntıll tı n arıes th g o ng f t gu a d th pr ximıty f th pre ced g sc nt llatıo al th l rver are al fected b comm ca s and are the ef re n t ındependе t Equ ti g p hal lıt es with l rved frequ ncies (an ther pp n matı n) Rutherf rd set N = Tp N_2 = Tp N 2 = Tp p wl en T N N / N The three equat n m v be sol d f p nd p but the e pr l abil tıe re pur ly fıtıtı u nd a e p rı n how ınaccess ıl le to perım tal verıficatı The model j t fied l y plau b l ty d c s

The sample space One p aks f pr l abıl t es nly connectı w th c n eptual (not ne e ar ıly p f rmable) exp r m nt and mu t fir t d f ne th po bl oute mes Th by n entı n to ng c It ı be d H or ta l T regardles f pe ıme tal or phıl ph al dıff lt the age of a p so ı t k n s e a t numb r nd e ch p t e n mbe tak a p ssıble g The w ing t dı e es lt n e of the 36 c ml at (1 1) (1 2) (6 6) An out me su h m 4 a mp und e t wh ch n be f rtl dec mp sed by en mer t n s m 4 oc t f th out m ı (1 3) (2 2) or (3 1) Th t e ces-sary t d tıng h b t een elem nt ry (and ı b) d mp d t mes or e ent E ch l m tary te me ı lled ample poı t the aggreg te ı th mpl pace Th con pt n l p m nt defı ed by the sample pa and t m t b t od ed d tabl hed t the ut t

Ex mpl (b) Th expe ım nt *d str l ut ng 3 b lls n 3 cells h 27 p s ble out om (mple p ntsl l ted tabulat n (1)

1	{abc|—|—}	10	{a|bc|—}	19	{—|a|bc}	
2	{—|bc|—}	11	{b|ac|—}	20	{—|b|ac}	
3	{—|—|bc}	12	{c|ab|—}	21	{—|c|ab}	
4	{b |—}	13	{ |—|bc}	22	{ b|c}	
5	{ac b —}	14	{b|—| c}	23	{ | |b}	(1)
6	{bc|a —}	15	{ |— b}	24	{b|a|c}	
7	{ b —| }	16	{—|ab|c}	25	{b|c| }	
8	{a|—|b}	17	{— | b}	26	{ |a|b}	
9	{bc|— }	18	{—|bc|a}		{ |b| }	

N te that b ll ı 7 ll may p ese t th d tribut f n hits am g 7 ta g t n f n a c dents n 7 kd y d o

Con ıd r xt the e p r m nt of pl ng 3 d tı g habl b ll t 3 c ll Wh th r o n t actual l all are ın lı tıngu hal le ı m levant they are tre te l a u h an l l s c n entı n tl r ıs now a spa e f nly 10 mpl ı nt It ıs l t d ın tal ul tı n (9)

1	{ |—|—}	4	{ | |—}	8	{—| | }
2	{—| |—}	5	{ |—| }	9	{—| | }
3	{—|— | }	6	{ | |—}	10	{ | | }
			{ |—| }		

( )

In playıng r ıl tt ea l pı ınt on a cır l repre s t a po ıl le ut me anl th sample p ce ı the ınterval $0 \leq \vartheta <$ Wl n one l rs the mot n f a partıcl under diff ı n e ry f ın tı n $x(t)$ represe t a n ı l f o te m anl tl sample pa e ı a m f l at l f ın tı n p e

Events In ex mın ng a f ıfge han l on may a k wl tl er ıt taın n e r atı fie a me otl r e d tı l prın ıpl ea h u h ent may l e le-scribed l y pecıfy g tl e ampl point wh l d a tı fy the tıpulat f n ıtı n Th e ry m p und event ı r pr nted l y an ggregate f sam ple poınt a d ın pr l al ıl ty tl eory the term ar yn nym s Tl tand rd n tat n f s t tl eo y r u ed t de rıl relatı n am ng ev t

S SET THEORY

C a ev nt A n may on l r tl e that A foes n t c r Th ı tl e n gat n or mpl m nt of A l n ted by A t n t f tl rpl pe t that do t bel g t A C e t o e ent A a l B th e t C tl t tl e A B r both e r tle u f A n l B l l ted by $C = A \cup B$ In pa t l $A \cup A$ th wl f ampl pac $\mathfrak{S}$ wı h th ef r p ev nt rt ntv Th v nt D both A n l B c r tle nt ctı f A a d B an l wr tt n $D = A \cap B$ It c t f tl po t omm n t A n l B If th re e n u h mm n poınt (a n the a of A A') A a d B c nn t oc r sım lt n o l an l tl y e all d m tu lly el wr tten $A \cap B = 0$ The v nt A l ut not B ımply $A \cap B$

E mpl ( ) In tab l t on (1) tl ev nt A ne c ll m lt ply c p ed the ag r gat f tl e po nt n mbe l 1 21 The e t B f st ell not mpty s th aggr gat of tl e po t 1 1 15 an l — Bec ry po t bel ngs e th r t A r t B (both) $A \cup B = \mathfrak{S}$ s tl ce ta e e t N xt $D = A \cap B$ c n t of th points 1 1–1 Fı llv A may be d ibe l s c ll empty

Probabilities in finite spaces If the sample sp c $\mathfrak{S}$ c nt n o ly N po t E E the r p ob b l tıe may be ny umber such th t $P\{E\} \geq 0$ and $P\{E\} +$ $+ P\{E\} = 1$ The pr b bıl ty $P\{A\}$ f n e ent A s the um of the p b b lıt e of all p nts nt n d n A th $P\{\mathfrak{S}\} = 1$ T find $P\{A \cup B\}$ o e con de s ll po nts belo gıng t e the A o B but tho e belo gı g t b th A n l B re c unted ly nc The f re $P\{A \cup B\} = P\{A\} + P\{B\} - P\{A \cap B\}$ I p t la f r m tu lly ex l s e ts the the dd t n ule $P\{A \cup B\} = P\{A\} + P\{B\}$

linked together can be used to form a variable focal length lens system called a zoom lens See ZOOM LENS

A thin pri m is one whose angle is so mall that the angle in radians is practically equal to the tangent Such prisms are used in ophthalmology and their powers are usually expressed in pri m diopters (*see* DIOPTER) The Risley prism system used for testing ocular convergence consists of two thin prisms mounted so that they can be rotated simultaneously in opposite directions as shown in Fig 2*b* When they are in the orientation sketched at 1 their combined deviation is zero when both have been rotated by 90 in opposite directions as shown at 2 their combined deviation is a maximum at intermediate positions their combined deviation lies between zero and the maximum but the plane of deviation is constant A similar pair of rotating wedges i used in certain types of rangefinders *See* RANGEFINDER OPTICAL *See also* BINOCULARS OPTICAL MATERIALS OPTICS GEOMETRICAL PERISCOPE RESOLVING POWER (OPTICS) [M H]

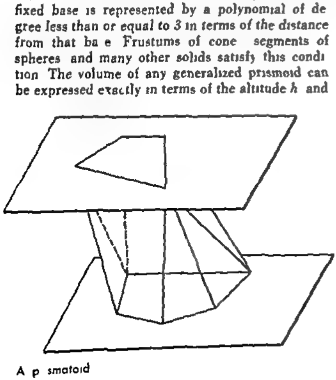
Bibliography D H Jacobs *Fundamentals of Optical Engineering* 1943 H Kay er *Handbuch der Spectroscopie* vol 1 1901

Prismatoid and prismoid

A prismatoid is a polyhedron all of whose vertices lie in two parallel base plane If the two ba e polygons have the ame number of ides the prismatoid is called a prismoid Among the prismatoids are included pyramids frustums of pyramids wedges parallelepiped and other prisms The area of a section of a prismatoid by a plane parallel to and between its base is a quadratic function (po sibly linear or con tant) of the distance from the plane to one of the bases A generalized pri moid is any solid for which the area of a section parallel to a fixed base is represented by a polynomial of degree less than or equal to 3 in terms of the distance from that ba e Frustums of cone segments of spheres and many other solids satisfy this condition The volume of any generalized prismoid can be expressed exactly in terms of the altitude h and the areas L M and U of its lower base midsection and upper base by the important prismoidal volume formula

$$V = \frac{1}{6}h(L + 4M + U)$$

See PARALLELEPIPED POLYHEDRON PRISM PYRAMID AND FRUSTUM [J S F]



A p smatoid

Privacy systems (scrambling)

Devices and methods for ensuring the privacy of overseas telephone conver ations handled by radio links Such privacy can be accomplished in a variety of ways two are particularly widely u ed at circuit terminals

The first method employs equipment for inverting speech to make overseas telephone conver ations unintelligible to the casual listener At the originating end devices change the speech conveying signal making high frequencies low and low frequencies high for example At the distant end synchronized equipment restores the inverted speech to its original form for delivery to the listener

A more complicated method employs filters to separate the transmitted speech signal into several narrow frequency bands Each of the e is then treated differently in a prearranged manner the relative positions of individual portions of the signal being interchanged in the frequency spectrum by inversion and transposition At the di tant end associated equipment puts the full signal back together in proper shape o that the listener may receive intelligible speech This method particularly if such changes are automatically varied every few econds make possible a radio transmission system that is very difficult to decipher *See* FILTER ELECTRIC TELEPHONY [C C DU]

Probability

Although probability theory deri es its notion and terminology from intuition a vague statement such as John will probably come is as remote from it as the statement John is forceful and energetic is remote from mechanics Probability theory constructs abstract models mostly of a qualitative nature and only experience can show whether the e reasonably describe laws of nature or life As always in mathematics only logical relations and implications enter the theory and the notion of probability is just as undefinable (and as intuitive) as are the notions of point line or mass An actual as ignment of numeri al probabilities is frequently unnecessary or impossible For example telephone exchanges are ba ed on a theoretical omparison of several possible systems only the optimal ones are built and the othe s d scarded Thus a huge in du try depends on theoretical models of exchanges which will ne er exist A simple ill stration of the nature of probabil ty mod ls is found in Lo d Rutherford s experiment

rand mly cho n pers n t e l rbl n l ca be as cribed p bab l ty $P\{A\} = N_A/N$ n l mila ly f th e e t H th t a pers be female o l as $P\{B\} = N_B/N$ If N_{AH} the mber f colorll d fem les the rat o N_{H}/N_H may be terpr ted s p bab l ty th t s d mly ch n f mal be c l rll n l Here th e perime t random ch ice in the pop l t on repl ced by a selecti n fr m th femal subpopula t n In the o gin l experim t N_{AH}/N i th p ob ab l ty of th m ltan us occu rence f both A an l H th t $N_{AH}/N_H = P\{A \cap H\}/P\{H\}$ Sim l r tu t n occur o f equ ntly th t it e n en ent to int od ce the otat on

$$P\{A|H\} = \frac{P\{A \cap H\}}{P\{H\}}$$

and t all th the ndit al pr babil ty of the e nt A r l t t H Th e cept s u ful when ev r it is des ed to re trict th n d ti n to thos a es here th e ent H occ rs (r wh re th hypothes H s fulfilled) Thu s betti g n an e nt A the k owledge that H oc urred w uld md ce o t repla $P\{A\}$ by $P\{A|H\}$ If all sam pl po t e eq ally l kely $P\{A|H\}$ till repre sents the r ti of fa r bl ca s to the t t l of cases pos ibl whe t s kn wn that H ha oc curred

Desp te ts mpl city the n t on of nd ti al pr b b ty s xceed ngly imp tant a d fre que tly the pr bab l t es in ample p e ar de fined nly i t rms f c nd t nal p b l l ties

E ampl (g) In a bolt f t y three m chin s manufactur m pecti ely 25 35 and 40% f the t tal. Of th r output 5 4 a d 2% a e d fe ti e bolts. Cl fic t on of th bolts c d ng t the mbe f the machi e and the qu l ty (d f r de ecti e c f n form g) g th x categ rie c d d nd d A a dom ch e f a l lt ult n f these t me but thei p b bilit es r not g en d rectly Inst ad the data l ting i th fi st m h ne se

$P\{d_1 \cup d_1\} = 0.2$ d $P\{d_1|c_1 \cup d_1\} = 0$ 5

t f ll s th t $P\{d\} = 0.0125$ and imil rly f th the point Th s xample may l s rve to ll t ate the r s ng f llowing Baye cer g th p b b l ty of c e S pp ng bolt wa f d t be d fect (hypothesis H) what th p b b l ty that it me from th first machine (A)? H e

$$P\{H\} = P\{d\} + P\{d\} + P\{d\}$$
$$= 0.012 + 0.0140 + 0.0080 = 0.0345$$

and $P\{A \cap H\} = P\{D\} = 0.0125$

Th th r qu d an w

$$P\{A|H\} = 0.0125/0.0345 = 25/69$$

In xampl (b) th p bab l ty f H b ll n th f t ll quals 1/3 d th pr bab l ty of A fi st c ll m lt ply ccup ed = /2 N w gi th t th ball th fi t l th c d t l p ba b r th t th cell m lt ply o up ed be omes 5/9 Th kn wled that H h u r d h uld re

on s real ne t bet on A By contra t f r th e nt B ball b r in the s co l cell $P\{B|H\} = 1/3 = P\{B\}$ a l the kn wledg th t H ha occurred g e n clue a t B Th r f r B a l t be in depe dent f H if $P\{B|H\} = P\{B\}$ th t if

$$P\{B \cap H\} = P\{B\}P\{H\}$$

Cl arly n th e $P\{H|B\} = P\{H\}$ s that H i al indepen le t f B Acc r l gly t o ent B an l H ar ind pen l nt f each ther if the pr ba b l ty f th r m lta ce rr ce f ll th m ltiplicat n r le $P\{B \cap H\} = P\{B\}P\{H\}$ This noti n carr es o r t a tem f m e than t e ent

Independent trials The intuit e frequency in terpretat n f pr bab l ty i ba ed n the c nc pt of exp rime t rep ated u der identical c nditi n a theor ti al model f r this c ncept can be devel ped

Con ide an xperiment lescr bed b a ample spa $\mathfrak{S}$ F r impl city of l g g it can be a umed th t $\mathfrak{S}$ on t f f t ly m ny ampl point E_1 E Wh e the same per m nt is pe f rmed twice t s cce s n th th l ll ut mes a the N pa f ample po ts $(E_1 E_1)$ $(E_1 E_2)$ $(E_N E)$ an l th se w c n t tut th n w sampl pac It is c lled th c mb n t ial product f $\mathfrak{S}$ b it If a d l n ted b $\mathfrak{S} \times \mathfrak{S}$ with ref re ce t an lyt c geom try n speak f th f t and s c nd coord nate f th point $(E_1 E)$ The n t n apply eq ally to t f t s mpl spa es an l t produ ts $\mathfrak{S} \times \mathfrak{S} \times \mathfrak{S}$ f m r th n t f ct rs F r ex mple the c t s n pl n f po nt $(x\,y)$ i th prod ct of the e l line by it elf In to ng c n n e $\mathfrak{S}$ ta ns ly th po nts H nd T t n the c n n t mes le ls to th n t ple product $\mathfrak{S} \times \times \mathfrak{S}$ wh p nt l a e n oord nates a l a f th f rm $(HT$ $T)$

Pr bab l ties m st be a gned t the events in $\mathfrak{S} \times \mathfrak{S}$ The a f d pe d nt tr ls ill be tr ated n the e t ect n if the e t trial i ndependent f th first the p bab l t es $\mathfrak{S} \times \mathfrak{S}$ f ll w the prod ct r le $P\{E F\} = P\{E\}P\{E\}$

I the a f n t ng of a c in th c l le d to th pr b b l ty ? fo each ample p int in agr ement w th the requi ement f equally l kely ca s The p a t ppro ch is mo e flexible and m r ge e al as h wn by th imp rta t Be n ulli tr l

E mple (h) B ulli t ls S ppo e e ch t i l r lts in s c e s S or fa l re F nd $P\{S\} = p$ $P\{F\} = q$ whe e $p + q = 1$ (Thi may be s d d a th mod l of a k ew o n) A suc es n of ndependent t i l f th ki d leads t the ample spa of n tuple $(SFFS$ $FS)$ and the p b bil ty f h a p nt i the pr d ct $(pqqp$ $qp)$ bta n d n r pl c ng each S by p and ch F by q

This m del ha ob ou appl cat ns t repeated bs rvat on and t gambling Independen e s an umpt o to be erified xp ime t lly Co t bly a o n ld b end wed w th mem y and id u f m e than 17 u c h ad That

Frequently considerations of symmetry lead one to consider all E_j as equally likely that is to set $P(E_j) = 1/N$. In this case $P(A) = n/N$ where n is the number of points in A (for a gambler betting on A these represent the "favorable cases"). For example in throwing a pair of "perfect" dice one naturally assumes that the 36 possible outcomes are equally likely. This model does not lose its justification or usefulness by the fact that actual dice do not live up to it, but for loaded dice a different model is required. The assumption of perfect randomness in games, card shuffling, industrial quality control, or sampling is rarely realized and its true usefulness stems from the experience that noticeable departures from the ideal scheme lead to the detection of assignable causes and thus to theoretical or experimental improvements.

How the success of probability theory depends on the disregard of preconceived philosophical ideas and on the readiness to adapt models to unexpected circumstances is illustrated by Bose-Einstein statistics.

Example (d). Bose-Einstein statistics. In the example of tabulation (1) the notion of perfect randomness leads to the assignment of probability 1/27 to each point. In the case of indistinguishable balls (tabulation (2)) it has been argued that an experiment is unaffected by failure to distinguish between balls; physically there remain 27 possibilities grouped in 10 distinguishable forms. This argument leads to assigning probability 1/27 to each of the points 1–3, probability 1/9 to each of the points 4–9, and 2/9 to point 10. This reasoning (sound in certain situations) has been accepted as evident in statistical mechanics for the distribution of r particles in n cells (Maxwell-Boltzmann statistics). Surprisingly it turned out that no physical particles behave this way and it was revolutionary when Bose and Einstein showed that for one type of particle all distinguishable arrangements are equally likely. This model assigns probability 1/10 to each point of tabulation (2). See BOLTZMANN STATISTICS; BOSE-EINSTEIN STATISTICS.

A useful although vague intuitive description of probability describes $P(A)$ as the relative frequency of the event A if the experiment is repeated many times under *identical circumstances*. The laws of large numbers render this more precise, but the description often lacks operational meaning. Experiments in agriculture and human sampling cannot be repeated under remotely similar conditions and in the case of telephone exchanges useful probability models refer to situations which will never materialize.

Probabilities in infinite spaces. Two examples may illustrate the novel features of this topic.

Example (e). unending coin tossing. In the study of limit laws one must consider potentially infinite sequences of coin tossings. The possible outcome of this experiment is an infinite sequence of heads and tails and every sequence such as $HTHTTH \ldots$ represents a sample point. Finitely many tosses are the beginning of an infinite sequence and the event "first four trials resulted in $HTTH$" is the aggregate of the infinitely many sequences with the prescribed beginning. Such an *event is called an interval of length 4*. There are 2^n intervals of length n and they are mutually exclusive. For reasons of symmetry one attributes the probability 2^{-n} to each interval of length n. Thus the assignment of basic probabilities refers to intervals rather than to points. A point such as $HTHT \ldots$ *is the limit of an infinite sequence of contracting intervals* H, HT, HTH, ... and therefore probability zero must be attributed to each individual point.

The probabilities of other events are similarly defined by limiting procedures. For example consider the event A that an infinitely prolonged sequence of trials never produces a run of at least two consecutive heads or two consecutive tails. It is more convenient to enumerate the points of the complementary event A' that two equal symbols do occur in succession. Clearly A' is the union of the infinitely many mutually exclusive intervals HH, TT, HTT, THH, $HTHH$, $THTT$ and so on. Here there are 2 intervals of length $n \geqq 2$ and therefore $P(A') = 2(2^{-2} + 2^{-3} + 2^{-4} + \ldots) = 1$, whence $P(A) = 0$. The indicated result of the experiment is thinkable but probability zero is attributed to it. A similar although more complicated limiting procedure leads to the law of large numbers according to which the event "the frequencies of H and T in the first n trials tend to 1/2 as $n \to \infty$" has probability one.

Example (f). roulette. Here the sample space consists of the angles $0 \leqq \vartheta < 2\pi$ and the notion of a perfect roulette assumes equal probabilities for intervals of equal length; thus an interval of length a carries probability $a/2\pi$. If the roulette is divided into 32 equal numbered intervals the event "even number" consists of 16 intervals and has probability 1/2.

The situation encountered here is not peculiar to probability but is common in measure theory. One starts with a collection of basic events, called intervals, and attributes probabilities to them. By simple and natural limiting procedures probabilities can then be defined for a much wider class $\mathfrak{F}$ of events which are obtainable by applying the operations of set theory to intervals (in finite or infinite numbers). $\mathfrak{F}$ is the Borel field generated by the intervals. Probability is simply a measure on $\mathfrak{F}$, that is, to each event A in $\mathfrak{F}$ there corresponds a probability $P\{A\} \geqq 0$ which is completely additive: If A is the union of the mutually exclusive events $A_1, A_2, \ldots$ then $P\{A\} = \Sigma P\{A_i\}$. The probability of the whole space is of course unity.

The extension of the addition rule from finitely to infinitely many summands may be defended by considerations of continuity, but ultimately this procedure is justified by its simplicity and its success.

Conditional probability—independence. Suppose that a population of N people includes N_A color-blind persons and N_H females. To the event A

r b l tion (1) w th pr babilny 1/27 I r eacl poi t A typ cal ra dom ar able i the m mler \ f o c i ped ell it a um the alue 1 at the three po nt mbe 1 3 the al e at tl e ght en p i t 4 21 a d the alue 3 t th s x p int i One a s the ef re tl at the pr b b l ty d tr l uti n f \ i g n b) $P(\ = 1) = 1$) $P(\ =)$ = ?/3 $P(\ 3) =$ /9 An tl er ar al l i tl numb r \ f ball in the fir t cell An in pect n f tal i l i (1) h th t it prol al ltv di tril t i gi by P \ = 0) = 8 ?7 $P(\ = 1) =$ 1?/ P \ 2) = 6 $P(\ = 3) =$ 1/ 7 O may al con der the t o ar al les m ltaneou ly a d f nd f re ampl that th e mb nat on \ = 1 \ = 0 oc c rs at t o point when e $P(\ = 1 \ = 0) =$ 2/? The pr bab l t e of all pa r g en l y the j int p ob l l ty d tril t n l \ and \ esl l ited in tab lat (3) Add g the e tr es t tl r w

Y \ X	0	1	2	3	D tr l u n c f \	
1	2/	0	0	1/?	3	
	6/?	6/2	6/?	0	18/	(3)
3	[illegible]	6/	0	[illegible]	[illegible]	
D trib						
[illegible] f \	8/2	1?/	6/?	1/		

and col mn gi the d tr b t on f \ a d \ espect lv and th y a e theref oe a t ll al d m g n l d t b t on

E ampl (t) mav b ed t illu tr t tl of cont u ndom a abl Thi e ampl n d ed tw o c t ve le t l p int in the int n l $0 < x < 1$ Let S b the ra d m r l le d ot ng th m l th t ch nd L th larg f tl two On ee that fo $0 < t < 1$ the e nt $L \leq t$ ha p ob l l ty t th ti ng $P(L < t) = F(t)$ g es $F(t) = t$ wh n $0 \leq t \leq 1$ l $t < 0$ a d f r $t > 1$ on ha tr i lly $F(t) = 0$ a d $F(t) = 1$ p ti el Th i tl d t il t f a ti n f L Fr m t e be al l ted all p l b l te s r lat g t L S m l ly the e t $S \leq u$ r p ese ted by the r g n t the nit q are l l w th l n $x + y =$ ther f r th d tril ut n f tio l S nam ly $P(S \leq u) = G(u)$ i g n by $G( ) = 0$ l ≤ 0 $G( ) = (1/2)u$ f $0 \leq \leq 1$ $G( ) = 1 - (1/)(2 -)$ f r $1 < u \leq 2$, a d $G( ) = 1$ f r $u \geq 2$ In l k m nn r th jo t d r but n f er n $P(L < t\ S \leq u) = H(t\ u)$ of th [illegible] L S a b al l t d

E ry and m bl Y has a d t ib tio f n $F(t) = P(Y \leq t)$ If Y [illegible] l fi tel m y al then $F(t)$ a tep f n t on Th th x mple $F(t)$ a m th lue 0 8 27 20 27 26 27 d l r pe ti ely i i terval $t < 0$ $0 \leq t < 1$ $1 \leq t < 2$ $2 \leq t < 3$ and $t \geq 3$ [h a the n t f d tr l t f ion u d ma ly l n f mt of l guag Th ot r ally n e i nt b $F(t)$ is n t ly nt u b t also ha d t $f(t) = F'(t)$ the $f(t)$ called th p bab l ty d ty of X I the bo e ampl the v t bl L h a d s ty defi d ly t for $0 < t < 1$ and 0 l ewhere tl e d n ty of S i 0 f r $u < 0$ and $t >$ it equal u f r $0 < u < 1$ an l eq al $- u$ f r $1 < t <$?

Tl n ti n f n l j end n carrie er two random arial l \ an l Y are independent if $P(\ \leq x\ Y \leq t) = P(\ \leq s)$ $I(\ )$ tl lt i e ily een tl at f r in l pen l [illegible] arial les with l tril ut n fun ti n $F(t)$ an l $C(t)$ tl li tril t ti n f nct n f th m $S = \ + Y$ gi n l y tl e c l ti n

$$P(S \leq u) = \int_{-\infty}^{\infty} F(u - s)\, dC(\ )$$
$$= \int_{-\infty}^{\infty} C(u - s)\, dF(s) \qquad (4)$$

In term f den ties Eq (4) rea l

$$h(\ ) = \int_{-\infty}^{\infty} f(u - s)g(s)\, ds = \int_{-\infty}^{\infty} g(u - \ )f(\ )\, d \qquad (\ )$$

In the r n l m h e m l tl oor lin tes f th point l en are ind pend t var al l wil tl e r t ngular d n ity $f(s) = g(\ ) = 1$ f r $0 < s < 1$ Th li tril iti n f th ir m S wl l la leen al lated al ca \ f n) al g Eq (5)

Expectations C en a ran l m ar al l \ n may int rpr t it di t l t f n t n $F(t)$ a d l ng the d tril iti n f a n t ma al ng tl real x u h tl t tl interval $a <$ $\leq b$ a rie ma $F(b) - F(a)$ In th s of a l er t ti al l m g tl e al e with pr l l il it j p tl nt r ma t e n nt ated at th p nt $(F(\ ) = f(x)$ t lt r pres nt tl r l n r ma le ts a defined in m hani Th nt r f g a t f thi m li tr l ti n i called the p tat n f \ tl al ml l for t $E(\ )$ l t pl y i t and ng nee n ta ti n u h a (\ ) (\ ) r $\bar{X}$ In tl e a es men t d el

$$E(Y) = \Sigma p \qquad n l \quad F(\ ) = \int_{-\infty}^{\infty} f(\ )\, d$$

In all a $E(\ )$ i gi en l y th Stielt nt gral $= x\, dF(x)$ (T be p i n pe k f ex p tati n ly wh n tl e ntegral n e g al o lut ly)

B f e di ng th ig fi f th n w c n pt a f w fr q tly u d defiuiti n ar aj t op i t Put $m = F(\ )$ Then $(Y - m)$ i of c i e a nd m r al l In mech ni t e n ctat n r j e ents th m ment of i e t a f the ma di tr buti In p ob b l ty it i c ll d er an f Y it [illegible] t ve root s the tand rd de a tion Cl a l

$$\mathrm{Va}\ (Y) = E(\ - m) = E(Y\ ) - m$$

Tl e a measure of pre d t s ro ly f the ent e ma on ent at d at th point m nd it r a e th mas m d away f om m In the a f two a iabl X a d X with x p tat n m nd m t i n es ary to on d not ly the tw a i n s $= E[(Y_1 - m\ )\ ]$ but al the a nc $\mathrm{Co}\ (Y\ X_2) = E[(Y - m\ )(Y - m\ )] = E(X\ Y\ ) - m\ m$ Th [illegible]

the sex distribution within families resembles Bernoulli trials is purely a matter of experience Many gamblers fully accept the independence and yet believe that they can influence fate by using systems for example by skipping the game after each failure or waiting for a run of 3 successes and so on The theorem on systems shows this to be a fallacy a gambler not endowed with foresight may use any system or random choice of the times when he plays or skips the game he remains confronted with Bernoulli trials and is exactly in the same situation as if he played at each trial *See* DISTRIBUTION (PROBABILITY)

Example (i) geometric probabilities In the interval $0 < x < 1$ a point is chosen at random This interval is the sample space $\mathfrak{S}$ and the probability of each subinterval equals its length The sample space $\mathfrak{S} \times \mathfrak{S}$ is the unit square of the xy plane and the probability of any figure equals its area The event the two successive choices result in a sum <1 is represented by the triangle below the main diagonal and has probability 1/2 The event the greater of the two choices is $<t$ is represented by the square $0 < x < t$ $0 < y < t$ and has probability t^2

Dependent trials Markov chains Many phenomena can be analyzed in terms of dependent trials In their description adopt the convenient and picturesque terminology of urn models which should not detract from the general nature of the scheme

Consider an urn containing N balls of which r are red R and $b = N - r$ black B Assuming perfect randomness the probability that a randomly drawn ball be red equals $/N$ If the ball is replaced and the procedure repeated the result is Bernoulli trials with $p = r/N$ Without replacement the sample space corresponding to two drawings contains four points RR RB BR and BB to which probabilities are assigned as follows If the first ball drawn is red (probability r/N) the conditional probabilities of R and B at the second trial become $(- 1)/(N - 1)$ and $b/(N - 1)$ By Eq (1) therefore

$$P[RR] = r(- 1)/N(N - 1)$$
$$P[RB] = P[BR] = rb/N(N - 1)$$

and

$$P[BB] = b(b - 1)/N(N - 1)$$

The trials may be continued and are equivalent to ordinary sampling

A more general urn model is obtained by letting the composition of the urn vary from trial to trial For definiteness consider the following scheme each time a ball is drawn it is replaced and c balls of the color drawn and d balls of the opposite color are added to the urn Here c and d are fixed numbers which may be negative This scheme contains interesting special cases such as the following

1 When $c = d = 0$ drawing with replacement occurs and for $c = -1$ $d = 0$ drawing without replacement occurs In the latter case the process terminates after N drawings

2 The Polya model of contagion is the special case when $c > 0$ is fixed and $d = 0$ Here the drawing of either color increases the probability of the same color at subsequent trials just as in a contagious disease each occurrence increases the probability of further occurrences This model represents only a crude first approximation to phenomena of contagion but it leads to comparatively simple formulas and has been applied with astonishing success to a variety of experiences from sickness insurance to baseball score

3 The Ehrenfest model for heat exchange considers two containers I and II and N particles distributed in them A particle is chosen at random and removed from its container into the other This scheme differs only linguistically from the urn scheme If the particles in I are called red and those in II black then each trial changes the color of one ball and gives the special case $c = -1$ and $d = 1$

The probabilities of the various possible outcomes in the general scheme are obtained as above For example $P\{RBR\} = (b + d)(r + c + d)/N(N + c + d)(N + 2c + 2d)$ and so on

Markov chains represent another important scheme for dependent trials Suppose that at each trial the possible outcomes are E E_N and that whenever E occurs the conditional probability of E_j at the next trial is p independently *of what happened at the preceding trials Here* of course $p_j \geqq 0$ and $p + p + + p = 1$ for each i The p_j are called transition probabilities The whole process is now determined if the initial probabilities at the first trial are known For example $P(E E_b E) = p_b p_b$ The probability of the event E at the third trial is obtained by summation over all a and b and so on Markov chain and their analog with continuous time represent the simplest type of stochastic process The Ehrenfest model considered above may be treated as a Markov chain by letting E represent the event that container I contains i particle Then $p_i = i/N$ $p_{i\,i+1} = (N - i)/N$ and $p_{ij} = 0$ for all other combinations of ij Other examples of Markov chains are the gambler's accumulated fortune the composition of a deck of cards under random shuffling and random walks Important applications are to queueing theory where one encounters also processes with more complicated aftereffects *See* QUEUEING THEORY STOCHASTIC PROCESS

Random variables and their distributions The theory of probability traces its origin to gambling and the gambler's gain may still serve as the simplest example of a random variable With every possible outcome (sample point) there is associated a number namely the corresponding gain In other words the gain is a function on the sample space and such functions are called random variable (In infinite spaces the idea is the same but a somewhat more cautious definition is in order) With the same experiment one may associate many random variables As an example consider the sample space of

Eq (2) defines Bernoulli s di tributi n becau e of ... Ne t n an b n m al coefficie ts which it m ol n i m t mes alled Newt n s f rmula It satu fies the following r latio s

$$\sum_{x=0} \quad ( ) = 1 \tag{4}$$

$$= \sum x w ( ) = \quad p \tag{5}$$

$$\sigma^2 = \sum (x - \quad)^2 w (x) = \overline{x^2} - \bar{x}^2 = npq \tag{6}$$

He the ta dard de iat on σ equ ls $\sqrt{pq}$

The phy t gards the emi s on of parti les fr m nucl of ph ton f om l ot bod e and of electr f om h t filame t as random phenom c trolled by p ob bility l ws One f the sim plest m thods f r t ting th s a umpt on is ba ed p n thes f rmulas Suppo e that a rad oacti e pecim m t p rt cle for a finite period T a d th t th mber i x By repeated ol ervations n th em of particles in a peri d of T sec onds, o e obta s a se ies f numbers x_1 x_2 x etc N w imag the p riod T ... be ubd ided i to a ery l rg n mber ... of i tervals each of length so th t $= T$ Indeed τ w ll be a umed t be so small th t, at mo t o e p rticle i em tted thin the nterval A ingl ob ervati n made during th t infin te imal i terval wo ld the efore yeld the e ult either n m i or emi ion let us y w th probab l ties p or q By hypothesi n u h b rvat o y eld x em i ns It i ee th ref e that th problem in l es a applic t n f Be no lli s d tr but o While it s d ffi ult to pec fy th v lues of p q and the result g en by Eq (6) m st ne rth le s be tr Si ce q ex t em ly m ll p i v ry nearly 1 H ce in iew of Eq ( ) $= npq = \quad q = \bar{\ }$ This lat n ha been test d e per m nt lly and f nd t b t e in all i t ces

Approximations In many practical pplicat th al es of a d n ar very large nd a di e t u e f Newt s f mula be mes imp il le be ... the b mial effici nt are d fficult t ev l t f l g x a d n The ex mpl f p rt mis i j t d c s ed s c e p int. U d th c rcum t ce t o appr imati n to N ton f rmul are a ail bl n deri ed by C F G s, the othe o e by S D Pois on d b g hi n m G s l w is the l m t ng f rm f Eq (2) when b th and n l ge so large m la e th t $1/\bar{x} = 1/ \ p$ d $1/ \ pq$ a b th n gli g ble This mpl s th t p and q a e n mbers n t t ally d ff r nt f m u ity In th t ca

$$\lim_{n\to\infty} w ( ) = \frac{1}{\sqrt{2\pi px}} \exp\left[\frac{-(x - \bar{\ })^2}{2p\bar{x}}\right]$$

$$= \frac{1}{\sqrt{2\pi}} \exp\left[-(x - \bar{\ }) \ / \ \sigma^2\right] \tag{7}$$

Th i G u l w

If p is so small that the mean np i of the order of unity in any gi en appli ... n Bern ulli s di tribution i then appr ximated by P i on s law which states

$$\lim_{n\to\infty} w ( ) = \frac{(np) \ e^{-}}{x} \tag{8}$$

The validity of this formula has also been confirmed in many instances f particle emi ion

The den ity fluctuations whi h occur in a finite volume of gas pre ent an inter ti g application of Gau s law S ppo e that a ves el of lume V onta ns but a ingle m lec le One may then sel ct a mall element f lume v and imagine s c e ive ob rvati ... to be made in rder to d termi e whether the m lecul i in this element r n t The pr babiliy of its bei g there whi h will be de oted by p i el atly th rati of the small ol ume element to the olume f the total c ntainer $p = v/V$ Now let n ol ervati ... be made p ... the olume ... The probab lity that in x of them th one m lecule i fou d in v i g ven by Newt n fo mula If the ... l c ntains not ne but n m le cules then the prol ab l ty of find ng x of them in i multaneously i the sam a that f fi ding th ne m lecule x times t i on ucces e occa i Therefore the pr babil ty f ob rving x of the n molecules in v is g en by

$$w \ (x) = C \quad p^x q \tag{9}$$

This formula may be appr imated by Gau s law Thus ... sub t tuti g

$$p = \frac{v}{V} = \frac{1}{k} \tag{10}$$

and $$q = 1 - p \tag{11}$$

the e re lt

$$w(x)\,dx = \frac{k}{\sqrt{2\pi n(k-1)}} \exp\left[-\frac{(kx-n)^2}{2n(k-1)}\right] dx \tag{12}$$

The exp ted me n a d the d pers n of thi d s tribution must be the ame a the corre ponding qua tities for B rno lli d t ibution H nce

$$\bar{x} = np = \frac{n}{k} \tag{13}$$

and $$\sigma^2 = npq = \frac{n}{k^2}(k-1) = \bar{x}\left(1 - \frac{\bar{x}}{n}\right) \tag{14}$$

If k is suffic ntly l ge $\sigma = \bar{\ }$ app ximately

It is often ... en nt to intr duce a qu t ty δ known th relat ve fluct ti n and defined by

$$\delta = \frac{x - \quad}{\bar{x}} \tag{15}$$

In iew f Eq (13)

$$\delta = \frac{kx - n}{n} \tag{16}$$

In terms of δ the l w of fl t ations takes on the

ance divided by $s_1 s$ is called the correlation coefficient of X_1 and X_2. If it vanishes X_1 and X are called uncorrelated. Every pair of independent variables is uncorrelated but the converse is not true.

If X_1, X ... X are random variables with expectations m_1 ... m and variances s_1^2 ... s the expectation of their sum $S = X_1 + \cdots + X$ is always given by $E(S) = m_1 + \cdots + m$; if all the covariances of X_j and X_j vanish then clearly $\text{Var}(S) = s_1^2 + \cdots + s^2$.

When X represents a physical quantity then $X^* = (X - m)s^{-1}$ represents the same quantity measured from a different origin and in new units. In the physicist's terminology X^* is the quantity X referred to dimensionless units. In probability X^* is called the reduced or standardized variable.

It was once assumed that every reasonable random variable has finite expectation and variance. Modern theory refutes this assumption. Many recurrence times in important physical processes have no finite expectations. Even in the simple coin tossing game the number of trials up to the time when the gambler's accumulated gain first reaches a positive level has infinite expectation.

Laws of large numbers To explain the meaning of the expectation and at the same time to justify the intuitive frequency interpretation of probability consider a gambler who at each trial may gain the amounts x_1, x_2 ... x with probabilities p_1, p_2 ... p. The gains at the first and second trials are independent random variables X_1, X_2 with the indicated distribution and the common expectation $m = \Sigma p x$. The event that an individual gain equals x has probability p and the frequency interpretation of probability leads one to expect that in a large number of n trials this event should happen approximately np times. If this is true the total gain $S = X_1 + X_2 + \cdots + X$ should be approximately nm, that is the average gain $(1/n)S$ should be close to m. The law of large numbers in its simplest form asserts this to be true. More precisely for each $\varepsilon > 0$ it assures one that

$$P\left\{ \left| \frac{1}{n} S - m \right| > \varepsilon \right\} \to 0 \quad \text{as } n \to \infty$$

This law holds also when the distribution function is not discrete.

As a special case one can obtain a frequency interpretation of probability. In fact consider an event A with $P\{A\} = p$ and suppose that in a sequence of independent trials a gambler receives a unit amount each time when A occurs. Then the expectation of the individual gain equals p and S is the number of times the event A has occurred in n trials. It follows that

$$P\left\{ \left| \frac{1}{n} S - p \right| > \varepsilon \right\} \to 0$$

that is the relative frequency of the occurrence of A is likely to be close to p.

Without this theorem probability theory would lose its intuitive foundation but its practical value is minimal because it tells one nothing concerning the manner in which the averages $n^{-1}S$ are likely to approach their limit m. In the regular case where the X_j have finite variances the central limit theorem gives much more precise and more useful information; for example it tells one that for large n the difference $S - np$ is about as likely to be positive as negative and is likely to be of the magnitude $n^{1/2}$. When the X_k have no finite variance the central limit theorem fails and the sums S may behave oddly in spite of the law of large numbers. For example it is possible that $E(X_k) = 0$ but $P\{S < 0\} \to 1$. In gambling language this game is fair and yet the gambler is practically certain to sustain an ever increasing loss.

There exist many generalizations of the law of large numbers and they cover also the case of variables without finite expectation which play an increasingly important role in modern theory. See GAME THEORY; PROBABILITY IN PHYSICS; STATISTICS. [W F]

Bibliography W Feller *An Introduction to Probability Theory and Its Applications* 2d ed vol 1 1957

Probability in physics

To the physicist the concept of probability is like an iceberg. The part of it which he uses and which is therefore in full view for him is but a small fraction of what is hidden in other and larger disciplines. The philosophy and mathematics of probability have become increasingly interesting and important through many current researches. See PROBABILITY.

Bernoulli's problem One of the most basic problems encountered in the application of probability to physics was solved by J Bernoulli. It concerns the probability of achieving a specified number (x) of successes in n independent trials when the probability of success in a single trial is known. Denote by p the probability of success; let $q = 1 - p$ be the probability of failure. The term

$$C = \frac{n!}{x!(n - x)!} \tag{1}$$

represents the well known binomial coefficient. The probability in question is

$$u\ (x) = C\ p\ q \tag{2}$$

For example one may consider an urn containing a black balls and b white balls; n drawings are to be made from this urn with replacement of the drawn ball each time. The probability that x white balls shall turn up in these n drawings is required. In this example

$$p = \frac{b}{a + b} \quad \text{and} \quad u\ (x) = C\ \left(\frac{b}{a + b}\right)\left(\frac{a}{a + b}\right)^{-} \tag{3}$$

S ppo o e wi hes to expl in why a ga e e ts a pres e pon the wall f a c nt in I e tre th m me t m I st by the m lecules per un t tim as th y strik a u t area f wall The m le- c les a e e y n me and th r m m ntt m l e y er tically fr m i st nt to i sta t f collis n a d f m p t to po t o th surface It i nece ry ther f re that me a e ag be taken Sh uld th a erage be r the d ffer t Th i which a I m lec le e p te ces i t m ? Or h ild n t k th a e age t gi en time o er the wh le e u de c iderat ? Clea ly there are many ay f c mput g th a erage ea h in I ing a part lar coll cti e in the af reme n ed e a d e h r q r ng a pecifi t n of el me tary prob b l t es

N w the e ce of mechanics does n t clearly d t t wh ch ollecti e is the pr p r ne to be ed nd the e i de hle I t tude f ch i e On of thes c llecti es wh ch has p n ed mo t suc f l th mbl f J W G bbs, will l e d ed b efly

Ph e sp The m t n of a i gle m lec le i described i terms of t var abl —it p tion a d t m m tum at ny g n time I the im plest c e f m t I g ngl a i f r xam ple th x a i t n mbers uffice to des ril th m t th y are the po it n *x* and the mome t m p II a pl is tru ted w th *x* and *p* I d ff n tw perp d l r a with n th t plane the m t of th m le ule i epr ent d by urve m th pl ne nd th pl i alled the pha e pa f th m g m lecule A m l cul wh e m t n i pl qu es *x y p* d p th t fo r numb f mpl te des ipt and thes four mbe s d fine a po t i a ph e pac f f d men s Simila I a molecule m ing in three-dimen n l pace h s ph n p e f x d m i (*x y p p* a d *p*) nd its dyn m b ha i d pi ted by a curve in thi s d m I p ce

Th id c n be g ne al zed a d pp I ed t co taining *N* mol ules The ph e pace of th ga ll h 6*N* d m ns d th m t of the n u g c p d to the t ajectory f a gl po t th 6*N* d m n l p e A gl p t th t d b th phy al nd t n f th n t g

E mbl s He G bb t d ed the n t of n mbl mag ned gre t n mbe f th r mod m y t m ll m l t th gi n ne If th l n b e l filled with g s h imag ned ry l g mbe f m l r el ll fill d w th th re q a t ty f the me g Thi ll ct f im y sel ll d a mbl E h m mb f th e mble w ll ha t f t ep se ted by po t m g 6*N* d m nal pl p d th wh l mble wh n ewed th t p w ll app l k a l d f d t wth h d d l d t part le f ll w g t own p th Th d n t f th l ud f d t w ll d ff f m pl t pla d will hang in time t ny g pl ce F m the l w f m ha t m y h

shown that th imaginary cl ud f d t l la e lk n ne mpr ll fl l

Ther i a set f c n l ti n l wev r inder which th cl id will n t cha g it d its in time e n th ugh it indi id ial p int are in m ti n One s h ndit n am i t f il e i t n f a spec al den ity d tr l uti n known as the can nical d tril ut n It l a th simple f rm

$$D(x_1 \quad p) = c\ n\ t\ nt \times \exp\left[\frac{-H(x_1 \quad p)}{kT}\right]$$

wh e e *H* i t tl e ergy *T* tl e t mperat e f th ga nd *k* i B ltzman n tant

At th p t t ntact i m d will the a l er c n d rati n All dynami al sa iall u l a ll pre tre f the preced g ex mpl which n ed t l e raged i o de to tre p nd t th l erv ables f th rmodynamic are t be aver ged r tl e prol l l ty di tril t n *D* Wl n th i d ne tl e law f thermod n m c f ll w in that en C ibl prol al il ty d tril ti n pr id an expla nati n f thermodynam c

Th e e f C ll tleory i cl al m h n c a r m rkal le In rd r t l a pl all I er t y t m wl i h f ll w il l f q an tum m hani e ta n modifi at n r n es sa y S BOLTZ IANN TATISTICS QUANTUM STATISTICS STATI TICAL MECHANICS STATISTICS

[H M]

Bibl og aphy R Carnap *I g l Found tio s of P babil t* 19 0 D te Ha r *El m nts of St ti t l Mecha ics* 19 4 R B l ind ay *Int d t n t Phy ic l Stat t* 1941 R B l a d y a d H Margenau *F i dati s of Physics* 19 7 R on Mi e *Wahr ch l chk its ech u g* 1931

Problem solving (psychology)

Th l i y ide t nal l el a i r ta ned l y n rgan m der t att i g l wh ch n t im m d at ly c e ll N atly d nti al pr ce es ha e bee d ti i hed l y diff rent te m dep nd ng p the c r um ce unde whi h th pr b- lem l ng takes pl ce U u lly th te m pr l lem l g ha been re tr ted i th st die wl i h req r th ubj t t manip late tool a m l l dev e d c r the ig f a ce of a d t u If n the th h nd th lut n ll f the r c g t n f a r l t sh p that i th id ti n l la s fi ati n f im l the p oc has be alled c nc pt f rm t d minati learn ng when b erved i nf ahuman an mal Whe th probl m t be l ed qu s the c r ti f a malfunct n f eq ipm nt the p ha been all d t o bl ho t g Wh n th pr bl m r qu re th betw en two r mo e alt n ti u f i th h been all d d m k g

Comp r t e p ych l gy h m d ume u c n t but n n t ly n th d cript n f the p b- l m l ng pac t e f l wer rga i m but lso ugge t g hyp th e as t th natu f the p oce m h ma be g In dd t n t th

simple form

$$w(\delta)\,d\delta = \sqrt{\frac{\bar{x}}{2\pi q}}\exp\left[\frac{-\bar{x}}{2q}\delta^2\right]d\delta \qquad (17)$$

Here $\bar{x}$ is the mean number of molecules within v and q is very nearly equal to 1 if $v \ll V$. Formula (17) is well supported by experiment.

Theory of errors. Perhaps the most important application of probability theory to exact science occurs in the treatment of errors. Measurements are accompanied by errors of two kinds, determinate and random. The former arise from actual mistakes either on the part of the observer or from faulty instruments; they are not susceptible of mathematical treatment. Random errors, however, because they are numerous, small, and likely to combine in linear fashion, are subject to the laws of probability analysis.

The Gauss error law. Let there be n measurements of some physical quantity resulting in the numbers $X_1, X_2, X_3, \ldots, X_n$. If the true value of the quantity (usually unknown) is denoted by X, then the errors are

$$x_1 = X_1 - X, \quad x_2 = X_2 - X, \quad \ldots, \quad x_n = X_n - X \qquad (18)$$

It can be shown mathematically and has been confirmed by numerous observations that the relative frequency of occurrence of an error x is represented by Bernoulli's distribution which, under the present conditions, takes on the form of Gauss's law

$$N(x)\,dx = \frac{h}{\sqrt{\pi}}e^{-h^2x^2}\,dx \qquad (19)$$

In this formula the parameter h equals $1/(2\sigma^2)$ and is called the index of precision. Clearly the greater the value of h, the narrower the distribution given by Eq. (19). The latter is often called the Gauss error law or the normal distribution of errors. In writing it the assumption has of course been made that the numbers x_1, x_2, etc., may be replaced by a continuous distribution.

The probability that a single measurement will contain an error between the limits $-a$ and $+a$ is

$$\frac{h}{\sqrt{\pi}}\int_{-a}^{a}e^{-h^2x^2}\,dx = \frac{2h}{\sqrt{\pi}}\int_0^a e^{-h^2x^2}\,dx \qquad (20)$$

The integral occurring here is called the error function and is denoted by erf (a); it is tabulated in most textbooks that discuss the theory of errors. The factor in front of the integral has been chosen so that

$$\int_{-\infty}^{\infty}N(x)\,dx = 1$$

Returning to the set of measured values $X_1, X_2, \ldots, X_n$, one may ask which is the most probable value (the one most likely to be true) consistent with this set of numbers? The answer is given by *the principle of least squares*, which affirms that the most probable value is the one for which the sum of the squared errors

$$x_1^2 + x_2^2 + \cdots + x_n^2$$

is a minimum (*see* LEAST SQUARES, METHOD OF). From this one may prove directly that the most probable value of X is its arithmetical mean

$$\bar{X} = \frac{X_1 + X_2 + \cdots + X_n}{n} \qquad (21)$$

Kinds of errors. The reliability of a set of measurements, such as the sequence $X_1, X_2, \ldots, X_n$, is specified by certain measures called errors, but in a slightly different sense from that previously employed. Three kinds of error will be described: the average error a, the root mean square error m, and the probable error r. All three refer not to a single measurement as did the quantity x, but to the entire distribution (19).

The average error a is the arithmetical mean of all individual errors without regard to sign

$$a = \frac{\Sigma|x_i|}{n} \qquad (22)$$

When the averaging process is carried out with the use of (19), one obtains the equation

$$a = \int_{-\infty}^{\infty}|x|N\,dx = \frac{2h}{\sqrt{\pi}}\int_0^{\infty}xe^{-h^2x^2}\,dx = \frac{1}{h\sqrt{\pi}} \qquad (23)$$

The measure of precision h has already been defined. It is an inverse measure of the width of the Gaussian curve, but it cannot be established without ambiguity from a finite set of measurements X_i. If the most probable value of h is calculated, it turns out to be the root mean square error

$$m = \sqrt{\Sigma x_i^2/n} \qquad (24)$$

Comparison with Eq. 23 shows that

$$a = m\sqrt{2/\pi} \qquad (25)$$

The quantity m is identical with what was previously called the standard deviation.

The probable error r is defined as follows. It marks that value of x which divides the area under the curve $N(x)$ between zero and infinity into equal parts. Hence r is an error such that a given error x has an equal chance of being greater or smaller than r. Mathematically, the value of r is found from the equation

$$\text{erf}\,(hr) = 1/2 \qquad (26)$$

The numerical relations between r, m and a are

$$\begin{aligned} r &= 0.6745m = 0.8453a \\ m &= 1.4826r = 1.2533a \\ a &= 0.7979m = 1.1829r \end{aligned} \qquad (27)$$

Probability in statistical mechanics. A complex physical system made up of many constituents, for example molecules, obeys the empirical laws of thermodynamics. Statistical mechanics is that science which attempts to explain these laws by an appeal to the laws of ordinary mechanics. In doing so it encounters problems of the following sort

m s th a qu t n f an o r all rul r r pl wh ch e able the organi m t r pond set th n h n a new pr l lem A m nke pe nted th a f d well t ay a d e el f the three ells r c e ed by an object Tw f the bject e de ti l all red c l es b t the thi d object r d ffe e t, a mall green c n Fo d is al ys pla ed nd r the dd l ject hence th ha bee called the odd ty pr blem If the an mal r gn eve al trial th these p rti ular ol ject hi p rf rmance w ll imp o e he will learn th at the re rd n der the g een c e After a number f trial the ubes and th e ne ar replaced with ther t f t identical bject and an odd bject If the a imal has onl l rned to espond t the green ne th f r t pr l lem his perf rm anc on th ec nd pr blem h ld be n better th ha n If on th ther hand th a im l h learned the rul that the food i under the odd bject, h perfo manc ho ld be l etter tha hs Th de cr pt n a a r impl ficat n e it u ll tak s xpe nce with many prob l m b f m t a mal w ll k w any e ide ce ll arn t. S th l arn ng et pa d gm h been dem tr ted n a number of a imal pecie it h been p po ed that t be u ed as a me ns of m k g int p es c mp ri n of ntellectu l ab l t

H m n b ing of c u a e pabl of d play g l a ing t. It qu te l k ly that this p oces nt f m h of man ab l ty t ge ral e a d to apply k ll l arned in o itu ti n to a ew pr bl m U f t tely man may l gen aliz nd pply n a ppr pri te r le t a new tu t nd thereb tak longer t ol the new probl m than if he h d had n rule

Group problem solving Gr p problem sol ing u u lly h s be n t d ed a f m f s c al p y h l gy Re a h i th s a ha l ee p pally in th ee f rm (1) th memb of the gr up a p rm tted f e mmun cat o w th each other ( ) th l es f mmu i ation a e e tr cted t perm t t dy f th eff t f nform t n flow n (3) th s bject pa t p t gam played a a t th r bj ct r the xp m nter m h e

Th m s m th d logical p blem wh ch till h n t been sat fa to ly l ed in the first arred a d mo t c mm f rm f g up p ob l m s lvi g O e f dament l quest on asked thus a of r ea ch s whethe ot tw h ad better th n At be t th prese t w an ly b th t t d p ds up n th c it r on f bet t r nd p th typ f p blem t be sol ed If th ol t n r qu the embly of a devi e r mech l puzzl i ob i u th t p rt of th dev a b h ndled by nly p n at a t me P ese t ev den e sugge t that up w ll be p to lo an ind d al h el pp oaches e n eded r when l g am t f i f rm t o ha t b two ed e lled and r l t d H wev r b u e f the nt rd pe de cies f th m mb of the gro p f l of e f th memb r a ad er ely affect the perf rma e f the entire gr up If th e crit ri n i the i n t prod ict p r man minute the indi idual u ually will be sup ri r t th e gr up

Individual differences Thi ri th ar a of re sear h in pr bl m ol ing c ncerned with the as se m t of al il ty differenc of i di dual through the u of test The u ual omnibu in tellig n e test a inad quate f r rese rch p ir po in th i area Only si ce th applicati n of fact r analytic meth d and the il equent devel pment of tests of primary m tal al ilities ha it been po il le t a es pec f c int llectual al l ties. The inf rmati n at present i sk tchy

A ries of tud es of y i ng adult of abc e a er ge int llig nce indicates th at at l t 40 d f fe e t fact rs are n eded to acc unt f r diff rence in intellectual ab l ty A diffe ent number f fac t rs or nti ely d fferent fact r may be neces ary t acco nt f r the tellectual al l ties of ave age adult a d ch ldr n In additi n to the difficulties of te t de l pment th re a e the p ol l ms of choi of type of factor an ly and cho ce of cr t rion f r th ex tence f f ct r (e In TELLIGE CE)

Heuristics Th i the tudy f the ment l proc es es in l ed prol l m sol ing The ari u stages in the proces f s l ng a pr l lem f r whi h th re i n immedi te luti appear to l as f l lows

F t ally the i di idual mu t c mpreh d the natu e of th pr blem The gestalt p y holog t argue f r th imp tance f th first tage t th y belie e that the manner in whi h a p oblem i e w ll dete mine t le t n part th likeli hood f att i g a ucces ful s l t n

Th seco d tage met mes call d the prep ra tion tage i dev ted to btaining i formation wh l appear t b r le nt t the final s lut n This lso a u tal stage sin e if th i d id al establ shes an inappr op te set or l i he m y re j ct a le ant nf rm t n wh ch is in fact rele v t A b s in f r of relevant inf mation i alm st a ndesir l l During th s tage the prob l m sol er tr e t amine all f th relev nt in f rmat n and n mpl cat s f l p blem B co e y f int latio h ps is n it elf addi t o al i f rm t o which may be levant

Th third st g s metimes called the inc bati t g i h ra t zed by th term nati n of a t e e k g f th desired sol t or and the t r g of tte tio to other matters It is usu lly de bed as a p s e period of hopeful wa ti g for i ight S c ssf l pr blem s l ng may f ll w a pe i d of pp r nt it at to the p blem be a the p blem l e h a o ded app opriate inf rma t n h ndl g b du g th o-called n uba t on p riod

The fi l t ge when the probl m l er ch eves the s lut o and mp he d it g fi an e s c lled n ght

Cle rly the pro of problem s l ing depe d up n m m ry f form ti n as w ll a imag n ti e

theoretical models offered by psychologists numerous nonpsychologists have contributed to the literature on the nature of the problem solving processes Some have suggested the name of heuristics for this field

Research in problem solving Problem solving in the restricted sense described above has been studied in human and infrahuman animals Some of the earliest research on animals dealt with the behavior of cats escaping from an enclosure rats solving a double alternation problem and primates discovering the use of tools Considerable controversy developed over the question of whether the behavior displayed by animals represented trial and error learning or insight Although this issue probably was not settled to everyone s satisfaction current research generally deals with other questions

One major research program was concerned with the tool using ability of anthropoid apes The animals had to discover how to use a stick as a rake to pull in foodstuffs placed outside their cages These studies *focused attention on the visual* perceptual conditions which affected such problem solving

Analogous experiments indicate that perceptual variables are also effective in modifying the problem solving abilities of human subjects One series of studies found that the subjects college students were more likely to solve a construction type problem if they had had prior experience with similar problems This was especially true if they were permitted to view this previous construction while they worked on the new problem

Trouble shooting of equipment has been studied *particularly from the standpoint of decision making* about probable sources of malfunction In one series of studies the subjects were given modified circuit diagrams and a display of symptoms the problem being to discover the malfunctioning component as efficiently as possible There is considerable evidence that the ability to trouble shoot can be learned

Several studies in human problem solving have dealt with a phenomenon called functional fixedness Comparable behavior on verbal or numerical problems has been called set or Einstellung Functional fixedness is defined as the inability to see alternative uses for a tool or object In one laboratory experiment for example a subject is instructed to make a construction using a matchbox and several other objects If the subject is given each of the objects separately he is more likely to succeed than if the objects are placed in the matchbox In the latter condition the subject may fixate upon the container application of the box and ignore its other uses

Concept formation Concept formation sometimes called concept identification or concept attainment is the process whereby an organism according to some self generated principle classifies as similar two or more stimuli which are objectively dissimilar Some of the ways in which a dog and a cat are similar for example would be that they are alive have four feet and have fur Each would represent different conceptual classes which could be generated by an observer Concept formation is important in the general field of problem solving because the problem to be solved may simply be the correct classification of stimuli for example which mushrooms are edible or which control knob shapes are most discriminable A somewhat more complex application of concept identification in problem solving is seen when the problem solver must decide whether the tentative solution he has attained is actually a member of the class of acceptable solutions

Three types of concepts can be differentiated in terms of the principle which must be generated by the observer For conjunctive concepts all the members of a class have something in common dogs cats and horses are all quadrupeds because they all have four legs For disjunctive concepts the class membership is not determined by one or more common elements The governing principle is that *the class members have either one attribute or another or both* several different substances can produce a rash and still be chemically unrelated For probabilistic concepts possession of an attribute is not a guarantee that the stimulus is a member of a class being depressed may indicate a serious illness but with low probability A persistent depression along with feeling of persecution and frequent angry outbursts more probably indicates the presence of serious illness but still there is no certainty

In order to make a decision concerning class membership the observer must receive information *about the stimulus to be classified* Information which is necessary to make the correct classification is called relevant information Information which is not necessary to make a correct classification is called irrelevant information It is analogous to noise in a communication system and may or may not appear randomly If the irrelevant information appears randomly it will be a considerable hindrance in arriving at the correct concept As the amount of irrelevant information increases linearly the difficulty of arriving at the correct solution increases at a positively accelerated rate since the number of possible combinations of attributes defining the concept increases exponentially

Most research in concept formation has involved the use of pictures or geometric forms as stimuli with either a motor or verbal response Recently a set of verbal stimuli in the form of nouns has been cataloged in terms of the frequency of particular sense impressions elicited by the word This material is gaining considerable use and may provide a breakthrough in the problem of studying the relationship between problem solving and language

(*see* VERBAL LEARNING)

Another kind of concept formation which has been widely studied in animals is called learning set This process sometimes called learning to-

Amo g all the li ng rders of mammal le- ph ts ar m t cl ely related pr b ably to a co (S en a) and to th hor tapi rl n group (Pe i od tyl) *See* PERI ODACTYLA FO ILS SIRE IA FO ILS [D E]

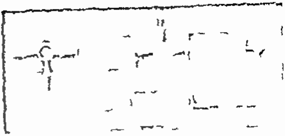
Procellariiformes

A o d r of oc anic bird characte ed by tu l lke n t il pen ngs well ed fe t de e pl image ften th pe uli r mu ky odor and ompound h rny h th f th bill I cl ded fam li are Dio- med d e (lbat o es) Pr cella i d e (p trel fulm r he r wat r) Hydr b tid e (t rm pet r l l a d Pel c n id dae (d ving petrel) The or d en mp es ext mes m re pa alleled only by the F) i rme ra g ng f m the wandering albatr (*D om d e la s*) with a w ng p e d of lm t 12 ft t the par w i ed lea t petr l (*Hal cypt mi o ma*) All p cie spend m nth at s e m ng t land a ely f e e x ept d g th breeding se n B th n ubati n d estl ng p iod tend to be ex pti nally l ng m th rd th f rme b ing up t 80 d y in th l g alb t s Food i p s r lated to f ody e a gang f om fi h squid and other marine i rt b ates t pl kt Some pecies p od ice ly s r tion of the tom h wh h together with partly d e t d food i ejected a a def n e mecha m S AVES [K C P]

Process control

A pec l f rm f feedback c trol yst m in wh h th l ment b ng c nt oll d a dy ami al y tem r fer ed to a p o s A p e ha quant ti h h vary with tim a d ar r lated b d ffe en t l m ti Wh le the t rm ha b en a ated p n p lly w th hem l a d petr h m al re n p e c ntr l al appl d t the a to- m c fl ght f m les th navig ti n f h ps th m m t of m h ne t ls the regulat n of q t t es h a l ct oltage ll d pre e t mpe tu reag nt e t t and a ity nd a h l va ty of dyn m cal sy tem r sub- y em The s nt al f n t n of a pr e n t l s tem d t al t th t f a y feedba k on t l y t m that th ma nte an of a stat f t t e a d di amic equ l b m b tw n the con t lled ar ble a a bl nd ef ren e ar abl r bl

P c tr l ystems e gle-lo p o m lu pl loop f dba k y t m The f gure how a m pl y t typ al bl ck d gr m of a s ngle l op cl ed l op process nt l r nfigu tion The b l me ts a t e p ce s be g nt olled th r ll output t du r wh h r as q the c tr lled va bl nd an e r n g der The a bles th p ce s ntr l y tem a the f ar bl M th cont olled a abl C d th ntr l r *E* Th n tput of th p c s co t oll r th ma p lated ar ble *M* f ct n of the p c t ll t mod fy th



Typ c l i gl loop p c s co t ol y tem

o tr l rr r and t produce a m nip lat d vari al le that will dri e the o tput vari l le to tl e de ired equil bri m nditi n relati t tl e refer en a i ble

D t irl n e wh h tend t up et the equ lil r um e nd ti n r ntrod ed i t th sy tem fr m a m mler of o ir es They ar h wn sche mati ally i i the fig ire e t ti g the y tem at p int *D* The y t m n i t m nimize it resp e t the e u d rabl di t rl n es and rema n at the equ lil r um d ti spec fed l y tl e set poi t or ref ren e riable Th pe if cati n f tl e proc e e ntr l y tem may i l l te dy tate ce i ra y tran ient p rf rma ce i re p n t a di tu l n or a cha ge in efer e i p it a d l w e iti ity t cha ges in sy t m con ta t e u ed l y nvir nme t l diti ns

Tl e p oces may inc rpor te a n ml er of b- pro e a p rt f th wh le F r in t if th o r ll proc i th flight f a n ile the a to- p l t mi il c mli at i th l pr ce On the other hand f th m le s n id red th p oce th ervome h ni m wh h a i iat tl e c tr l surface a e f pr ces e In tl er ca e the func t s of th pr e r bpr ce tr lle are go erned by the same g al n iderat

T hav a rati al d ign procedur f r p ces ontrol y t ms it i ne e a y t ht n r esti mat the diffe t al q at n that el t the ma n p lat d (ind pend t) ari bles t the con t ll d (dep nd nt) a bl s Tl e diff en t l equation may b linea n nlinear If they a e l near t is p bl to expr s the proc ha acteri ti mpa tly by a tra sfe fun t n wh h s u ed t der e the r quired n nt lle tra fe f n tion by the tandard method u ed in fe db ck n tr l sy t m F a d cu ion of th th ory e CONTROL SYSTEMS

Th m re n ti nal appl cat n f th term proce contr l efers to the nt l f a ch m) proces o of the many ariable wh ch aff ct its p gr Th l tter in l de am g th s ch i ble a p ssu t mp rature l quid level fl w rates age t c nc tr t n and pe d of t t n f mech al el me t In a proces th e q a tit m y b aut m i ally controll d a s b- p o e s s th t the m n pr ce is kept n a st te of q l b i m *Se* CHEMICAL PROCESS CONTROL PRESSURE CONTROL AUTOMATIC TEM ERATUR CO TROL AUTO IATIC

and creative handling of the information See LEARNING THEORIES MEMORY [E J A]

Bibliography J S Bruner J J Goodnow and G A Austin *A Study of Thinking* 1956 K Duncker On problem solving *Psychol Monograph* 58 no 270 1945 W Kohler *The Mentality of Apes* 1926 M Wertheimer *Productive Thinking* 1945

Proboscidea

An order of mammals including the elephants and their allies Probo cideans first appeared in the Eocene as small pig sized creatures the moeri theres and during the remainder of the Tertiary the stock underwent an extensive and very com plex evolution At one time or another probo cid eans lived on all continents except Australia Two main lines of evolution are evident the dinotheres and the elephantoids The dinotheres were char acterized by peculiarities of the skull and dentition The lower jaw bore a pair of heavy tusks that curved downward and backward The elephantoids are divided into three families In the long jawed mastodons typified by *Gomphotherium* the lo ver jaw was much elongated and there were tusks in both upper and lower jaw The short jawed masto dons which lacked tusks in the lower jaw include some of the best known fo sil vertebrate The true elephants characterized by very high cheek teeth include the mammoths and modern elephants See EUTHERIA PROBOSCIDEA FOSSILS [D D D]

Proboscidea fossils

Proboscideans probably originated in Africa and spread to all continents except Australia Like their few living de cendant ancient proboscid eans were large plant eating quadrupedal mam mals that walked on pillarlike legs All except pos sibly the earliest known form in the Eocene depo its of Egypt *Moerithe ium* had an elongate probo cis (the trunk) They also had upper and sometimes lower tu ks that were enlarged econd incisors Fo sil forms are classified chiefly by shape of the jaws and teeth including the tusks and by the character of enamel configuration in all the teeth

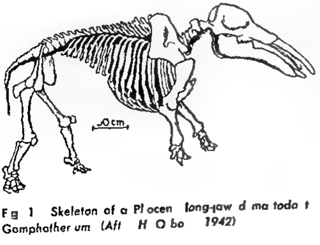


Fig 1 Skeleton of a Pl ocen long-jaw d ma todo t Gomphother um (Aft H O bo 1942)

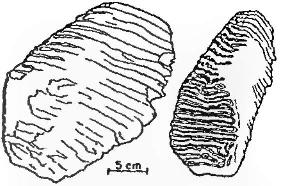


Fig 2 S de and occl sal v ew of the upper th rd molar of a Ple sto ene mammoth from Ill o s (Afte H Osborn 1942)

The tapir sized *Moeritherium* shows many re semblances to the phenacodonts in the order Con dylarthra and indicates that proboscideans prob ably came from phenacodonts This evolutionary conversion probably happened in early Eocene time See CONDYLARTHA

Certain peculiar probo cideans the Deino theriodea have the anterior part of their lower jaws abruptly down turn d Deinothere lived in Eurasia and Africa from Miocene into Plei tocene time Another group the Ma todontoidea (Fig 1) includes a great array of forms of the Miocene through Pleistocene in North America Eurasia and Africa and the Plei tocene in South America Mas todonts usually had low crowned cheek teeth with tooth cusps arranged into transverse lophs (at right angles with the front to rear axis of the jaw) Some ma todonts (*Phiomia Gomphotherium Tetralophodon* and others) had elongate lower jaw Their lower tusks extended forward and probably served as forks to uproot clumps of ve etation upon which these animal fed Long jawed masto donts like *Platybelodon* and *Amebelodon* had flat tened lower tusks that may have served as hovels to scoop up mas of soft water plants Another group of mastodonts *Anancus Stegomastodon Mammut* and others were short jawed and had no lower tusks Stegodonts generally intermediate be tween mastodonts and elephants had elongate low crowned molars crowned with numerous trans verse crests

The family Elephantidae (true elephants) had short lower jaws without tusks and their high crowned cheek teeth had the enamel dentine and cement arranged into trans erse plates This is in terpreted as an evolutionary adaptation that ena bled the teeth to withstand a greater amount of wear resulting from a diet of abrasive egetation such as dusty grass and tough hrubs The elephant family includes mammoths (Fig 2) D ring the Pleistocene mammoths tra eled to all the onti nents except Australia and South America The famous woolly mammoth *Mammuthus pr mige nius* is well known fr m carca f und in the frozen mantle rock of northern U S S R and Ala ka

Fig. 3 Typ l N rth Am co t e f og th g tree frog Hyl c o (l ft) o d th g oy tre f og H lo (ght) (Am c M m f Nat l H story ph t g ph)

Centrolenidae In the American t op c l f nd a m ll gro p of three gen ra and abo t 20 species of m ll t l ent arb real fr g grouped to g th r n the family Cent len dae A peculiar cha t t of some pecies th t th bo es re green. S AMPHIBIA SALIENTIA [R G.Z]

Procyon

Alpha Ca i M n r is a earby b ght star 0 3 m gn t de f p t al type F5 Located at a d s e f 3.5 par P y n ha an abs l te mag nit de of +2.7 h ch sl ghtly brighte than a n rm l m i seq en e F5 tar Thus P ocy may be an ld tar th t h b gu to ev l e off the main qu It gr t g d ated by a l se faint compan n of ol t magn t de +13 yellowi l r th t i wh t dwa f tar wh h i near ing the d f t e l t n Th s u l b nary orb t f 40-ye r p iod g es Procy a m s f 1 76 a d t e mpan n 0 65 th t f the Sun Se STAR [J L GR]

Product design

P odu t des gn is the d t rm n t on and p fica ti f the parts f a p du t nd thei i t rr l t h p o th t they be om a unified whole The des gn m t atsfy a b o d ray f eq i ement i e d ti of bal nc d t n A prod ct s design d t p f m particul r fu ct o r et f f n i n ff ct ly and l ably t b om a ly m nuf tu bl t b pr fitably alable t sat the p poses and the ttitude of the c mer d i b d bl f d e o m l to per t F n ta th d gn mu t tak to ns d t n th p rt ul m n fact i g f l n s ail able m t ri l k w how and e onom re urc f the m l t r Th p d t m y d t b p k ged ally t will al eed t b shipped th t it h ld be l ght we ght nd tu dy f tru tion The p od ct ho pp gn fi nt, ffect omp t ble w th th c lt nd pp a to be w th mo e th n the p c Th em ph s m d ff r w th th n t c D rab l ty n a p per n pki is different from d iral ility in a p wer l o el

To determine wh ther a de ign i well adju ted t the g o s array crit ria are needed Some are objecti e and mea ural le uch a clearances and eff i ncy while others are qu te ul tle and even s bjecti e In a way product de ign i an indu trial art

Ultimately the purp e of prod ict de ign is to a ertain that the prod ict will at fy hum wants and wi he e th r directly a c n umer good or ind re tly a capital equipme t or comp nent

Except in tl e ca e of l a ic in enti n prod ct de ign i a rede ign t it ch ng d condition c ite ia or enlight nment Ch nge may appear caprici u a in me f hi n a d t ys may be the re ult of technological p gre s or may re lt fr m a change in attit de toward the product r it functi n In me a ea trend can be d c vered but future preferences of bu rs m ist be predicted gambled on r f rced to occur

Th re are vari n steps in product des gn which are n t neces arily i part cul r rder Tl v are a alytical stud es c ati e synthe drawing and model f r appe ra ce fi nct on and specifica t on plus calcul ti n experiment and te t S e PRODUCTION ENGINEERING [R T P]

Product of inertia

Th product f inertia f area A relati e to the i dic ted XY rectangul a es i $I_{XY} = \int xy\, dA$ (F g 1) The pr d ct of in rtia f the ma s con tai ed i lum f rel t e t the XY axe i $I_X = \int xy\rho\, dl$ (Fig 2) S mil rly f r I_{YZ} a d I

The pr d ct of ine tia f are lik moment of in t a me ur d in quart c lengtl u its such as ft for ma it s m asured in m m lt ply ng l ngth qu ed u t a g cm Unl ke m ment of nert a the p duct f ine tia may be p t e or eg ti

Relativ to pri p l axes of inertia th pr duct of n rtia of a figure s z If a fig re is mirr r

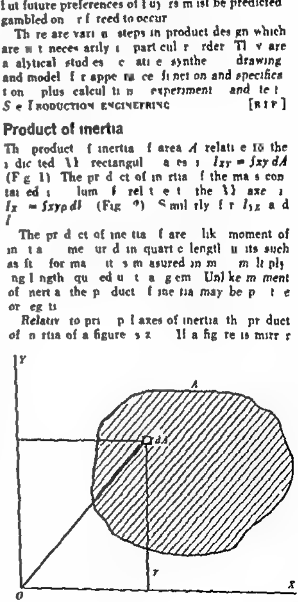


Fig 1 P d ct of rtia f a

In evaluating or designing a process control system consideration is given to start up characteristics stability steady state characteristics transient response insensitivity to disturbances and other factors Most processes require a start up period during which they progress from a state of quiescence to an active state In a chemical process temperature flow pressure speed valve settings and other factors must be brought up to the condition or equilibrium that permits the chemical reaction to start In missile control a missile just fired from the ground require a period of acceleration during which its properties are rapidly changing until it reaches a speed high enough to permit normal control procedures to be effective Satisfying these initial requirements automatically is probably the most difficult part of process control design because the governing relationships are time variant or nonlinear The other design considerations are similar to those encountered in all feedback control systems and are handled in the same manner [J R R]

Bibliography J G Truxal (ed) *Control Engineers Handbook* 1958

Procoela

A suborder of the order Salientia characterized by a procoelous vertebral column in which each vertebra is concave anteriorly and convex posteriorly and with a free coccyx articulating by a double condyle This suborder commonly includes five families of frogs Leptodactylidae Bufonidae Atelopodidae Hylidae and Centrolenidae The families Dendrobatidae and Pseudidae also are sometimes recognized

Leptodactylidae The leptodactylid frogs are most abundant in number of genera and species in the American tropics and Australia with a very few species found as far north as the southwestern United States and New Guinea A single genus in South Africa possibly belongs to this family There are over 40 genera of leptodactylids with more than 500 species over 200 are in the genus *Eleutherodactylus* alone Evolutionary lines within the family have undergone extensive adaptive radiation so that one or another species lives in almost every fashion known to frogs Species with similar habits are often similar in appearance too so that leptodactylid frogs are often almost indistinguishable externally from a variety of species of other families

Fig 1 (a) *Oreophry ella* [illegible] *elch* an atel p p d (b) *Elos o nas s* [illegible] *leptodactyl d* (c) *B a hycephal eph pp m* an atelopop d (*F om G K N bl The Biology of the Amph b a* Dove 1954)

Fig 2 *The Pa aman an po on f og D nd obates au at s (Am r can Mu eum of Nat ral H st ry photograph)*

Bufonidae Members of the large genus *Bufo* the true toad are native to virtually every place in the world where frogs live except the Australian region The other four genera of the Bufonidae are found in Africa and the Malay region The four genera are of little numerical importance but one of them *Nectophrynoides* of East Africa is of interest in being the only ovoviviparous frog All bufonids lack teeth and the true toads of the genus *Bufo* are for the most part rather warty short legged terrestrial animals that enter the water only during the breeding season

Atelopodidae The Atelopodidae or Brachycephalidae is a relatively small family with 10 genera and about 90 species in South and Central America Two genera in west Africa and another in the Malay region may belong in the family Many of the atelopodids are small brilliantly colored frogs Members of the genus *Dendrobates* (Fig 2) produce a skin secretion used by South American natives to poison arrows

Hylidae The Hylidae or tree frogs (Fig 3) is one of the larger amphibian families with nearly 500 species known The major ty of these about 350 species belong to the genus *Hyla* which is found in both eastern and western hemisphere Many of the Hylidae are adapted to arboreal life having expanded digital disks that facilitate climbing but not a few have adopted other modes of existence and lead terrestrial aquatic or even burrowing life

ta ls ar an e ed if only tentati ely the m jor j b of d igni g the t t l pr ces beg The h l m fa t r ng pr ces u ually l es withi th realm f d t l e g neer p od ct g n g deals with the mechanical a pect of ma f t r ng pr ce i ipme t tools and d es l ary equ pme t h a fixture ga ges d th l ke a d with spec ally desig ed eq ip m t h as con eyo tr fe equipment a to- m ti embly ma h es and i pect on equip- m t T l d n and mach e design are ften m e pecial ed f nct in the r wn right Like- e trument t d e ntr l de ign are ther pe al fields.

Afte the a lytic l quiry i t the det iled mea the ord of pe forma ce r ope ati n e- q e e i det rmined Th que t l tudy e ds a fl w diag m wh ch sim la r ppleme tary t the fl w proce hart nd pr l minary t pl nt l ut if ch g n lay ut ar eces ry

The e a gr t d ge e i dust y Pr d c tio e g e g may r quire th g m re tha set p and hedul g i tomat c ew ma ch e o w fo m g m hi l the in t n es the ti of wh le ew f ctor es with p l equ pm nt m y b r quir d

Coordination of man and machine At th phs. th edg f p od ct gi ee ing d i d tr l e g g diff e w th ea h oth Ind tr l e gin e g s c erned with methods l bo co t d st da d but wh e meth ds b c me h ghly m cha d d m nat man l w k ar utom t the pr blem be me ma ly es f mach e de gn a d th efor are i the ea f p d ti eng ee i g F m ind tr al gi eer g tum d ta th re may be d t s t a me- han lly o t d e g ee th t t w uld be f asi bl t l st ec m lly to ea ch for m mech n l m ns t pe f rm certa operat The e shifts f om p ly du t al eng nee i g t an atiu d tow d p d cti ng ee ing M ny d ce p f rm s ch pe ti ns s t an fer nt, d ff ti te a d a mbl The oper ti d fi t ly nd f d t l g eer ng d the d t l e g e may i d te th r se but th i t ll t d dj tm t to th t t l p od t n p du u u lly s a mecha c l ing blem h n e du t i l ng e i util th me han c l b f th p d t e gmee

F l ng time th de gn i t ll ti n a d t l f n ey d a t m t c q ipm t tha d d m nuf t g d h e th me han cal p o- d t g a d th d t al g e ha e w ked t g th The g ate th t m t th mo e diffi lt t to p ate the m chi e de g e a d the p odu t e g f om the dust l eng er in th fu t al p s t n t m uf tu ng. It p b bly f t gn t m h n d gn e rt d d l d t l d c mpo t a d t d t l g g th ll pl n P d t n g r g the f ll b twe n a d t h both.

If it i f und de irable t d ign special eq p ment f r prod cti n and if the equipme t i par tially perated m nually pri ciple of huma en g g ind cat h w the oper t r can m t eff cti ely perate it The equipme t i in a s e an exten i n l the peopl The f r e h tan speed accura y and th e der tand ng of the operat r a e the l m ting dim n i n and f ct r of the eq ipm t The eff iencie f people in thes ope t n dete mine the efficiency f the equip- ment The equipment l ould l e de ig ed so that the perat r i m t eff nt

Introduction of automation In n wly de igned equ pme t pecı lly aı t matic c mpl x ma chi es mod l are ften l lt to fi d and el m n te bugs and t ol t in dat con ning time and cura y Often n w prod ct req ir new p ces es which mu t l e de l p d in laborat rie or prot type m del Al o nle a t mat c eq ipme t i completely rel l le p c h t ld l allowed in the line f r s b tit t n of ma al l bor i ca e f a l akd w wh h w ld l an expen si e bottlen ck a d co ld cl e a l e f day

I ind tri wl e a t mat n i well devel ped whol l nes re b ilt a pr l types p rated to se ur synch nizati n t de el p spec al skill a d t tudy the pr ces f r r finement f el m nts d their effect e i t ra t n nd f r pt mum ppl at l me ind trie th wh le produc tion et p i e m ch e a d m t le st died a d er ted s a t inte act unit The t tal ma h e has mech ni l elect ical l ctr ni hy d aul a d p e mati comp ent op rat ng to- gether a t m tically Th produ t on character s ti f h machi e ca n t l determ ned f m th ch act ist f the e separate p rt Th e ch racteri t cs a f d by ope ating models often in f ll s le nd compl te det l

Improvement and coordination The front er f p od tio g n e i i in de i g mo e and impler utomat c m ch e The m re me ha i ed p e b comes th m e t i f eed f om the l m t t s f h man per t r d th s the mo e bl t bec me to mech ni e t furth Be u e i o ti s effect th d idual tie p- a h f the e g n er e e l diff r nt p oce o m ch m y be de l ped th d the s me j b equ lly w ll th t eq ally f t ffic e tly de mic lly

Clo e nt l f th u e f machi e and de- t iled reco ds f the p rf rmance nd s rv c a i d t wh r mpr me t w ll b mo t effect e i n e g p d ct ty A t ch logy rea mpl ity th a ti ti s th t e te i t t b me m spec l ed nd the e d f r rd na t d c ato g ows T pe f m h pe l fun ll n effi ie tly the p odu ti n e g e needs t p rt pate n nf nc a d pl n g e i ns with p d ct d el pm nt e g n e s nd f t ry pr d ct o m nager

F rce t w d ob l n f om ew m ter al t n w wp nt e d eq pme t n ffi e t b f i it w s o t n th phy al P od t

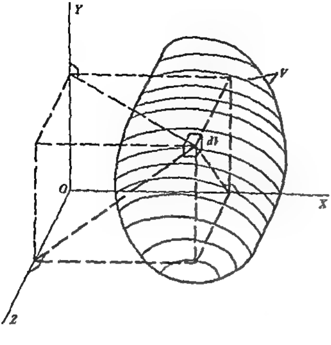


Fig. 2 Product of inertia of a volume

symmetrical about a YZ plane $I_{ZX} = I_{XY} = 0$ See MOMENT OF INERTIA [N S F]

Production engineering

The planning and control of the mechanical means of changing the shape condition and relationship of materials within industry toward greater effectiveness and value Production engineering is a relatively new term applied to some aspects of planning and control of manufacturing it is a service function to the production department

As industry and technology evolve to greater levels of sophistication complexity and specialization the broad area of figuring out what to do becomes more involved and at the same time better understood By this process some of what had been originally performed by either the production department or the industrial engineer becomes a separate activity with its own background of knowledge principles and techniques

Planning and purpose Production engineering as a planning activity takes place between product design and the planning of the over all manufacturing process Over all manufacturing planning is usually considered within the profession of industrial engineering But in attitudes of greater specialization production engineering may be considered a separate profession closely allied to industrial engineering

The purpose of production engineering is to refine and adjust the design of the product (preferably with the product designer) to the problems involved in its proposed manufacture and conversely to solve certain problems mainly mechanical such as those involved in processing tools dies and new or special equipment necessary to manufacture the product efficiently and according to the established specifications

Position in the organization Product design production engineering and industrial engineering overlap variously according to the situation policy and organization The techniques of production engineering are mainly in the field of mechanical engineering but some are closely related in concept and performance to if not directly derived from industrial engineering

Intelligent activity in production engineering requires a comprehensive understanding of both the intention and meaning of the product design and the means and principles of industrial engineering The production engineer often acts as liaison between product design and industrial engineering

The product design department specifies what is wanted usually making only a general statement of how such specifications are to be met The particular means are the problem of the production engineer Product design takes into consideration performance life safety and other functional requirements usually fully testing models of various types for these features In many product appearance and other sensory qualities have been adjusted These too must be maintained

Initial phase After studying the over all product the product engineer examines every detail of each operation for forming each piece Various lines of inquiry are followed Is the specific shape the most economical in material labor and equipment? Is it compatible with either present or obtainable equipment and know how? Are components readily obtainable if they are to be purchased?

Usually the product designer has valid reasons for each detail but he may not know of the benefits of alternate means so the production engineer may often make diplomatic inquiry into any detail that appear difficult expensive or superfluous Prudent organizations avoid the condition in which the production engineer accepts the design specification as absolute and final and the opposite where the production engineering staff can make any changes at all to suit easier processes or methods There is usually a common sense ground in between that can be found

The first operations in production engineering are to examine every detail in relation to its feasibility and economy with respect to the peculiar situation The first question most likely to arise is whether to manufacture the part or purchase it This is not always an easy question to answer It depends upon many factors from over all utilization of facilities and labor to company policy For instance many industries have expanded by vertical diversification into being their own suppliers Like much of production engineering the answer to this lies within the policy of top management and their vision of where they are going in the light of competition economics technology and cultural change Peculiarly here production engineering must cooperate with sales finance and even basic research

Development of over all production The first work is analytical inquiry After most of these de

th g e nme t Bureau of Standard y rof i nal ociet es r lead ng m nufa tur r (se DESIGN STA R RD)

St d rd material and pa t and tandard z d mpo ent le d t nterchange ble man ifact r g Ea h compo e t of a pr duct made l tl t fit th t mati g p rt a l t meet a g n pecifica ti nd the pecifi ati n e so that any part so m de n b i t ch g d with the r g nal

Int h n eable manufact re s th un ferly ng princ l that perm t m pr d ct By making m ket f m inte changeabl pa t El Wh tn y ho d that a great quant ty of an article can be prod d at qu lity mproved n l t pr e re du ed

I t r ha g able manuf ct d e not neces sa il r lt n a ta dard ed pr duct St nd rd ized p rts and c mp n nt can l a emb led in a a t f d ff rent oml nati Cur e t model of pop la a t mob le off r s many j tt n f r ex mple that the m nuf ct rer ould hardly pro du n th l f of the m del all the i l natio th t re m r cally p ble

Production equipment Ma h e y th t ct ally ha ges th hape or har cter t of the tarting mater l th p od t n equ pment Alth igh th prod t de and m te al g all dictat h t pr e t be u ed the a a labil ty uit bility nd co t f th equ pment t e it tl p ore s d fi t l y affe t th deci n In th final an ly s the cho of pr du t n equ pm nt t d the j b dep nd t the pr ce lect d (see MACHI I G OPERATIO S METAL FORMING)

P od ct o q ipment in lude m ch ry wh h the act al mecha ical d ice w rk ng prod ct, a d equ pment, wh h cov s items le pa t b th, ven tank n eyor pr ure vessel and the d d tly in c nj t n th p at pe f m d on the mate l In ad on th s gr t at ty in a e ut lity se e eq pme t i a s i du t ial f lity

P od t equ pment may b cla ed a ge eral urpo o p c l The f rm r i un er ally ap lied t m y m t r l pa t the latt i de igned t do p cifi j b ally n o e p rti lar pa t

Capa it f p du t n quipm nt f equ ntly m t a pl nt s pe at o The ap c ty alo g with b b l ty t ke p equ pme t utili d r m p r n a ptimum am unt of t me det m n s ts tod t ity

Tools and accessories Smaller ly deta ha le p ec f ma h y or eq pm nt ed d tly pr d t c j nct with the p odu q pm nt e t l ard ce ries Ha d tool m u l o p er d j g fi t re attach m t tr l hopp r p p nd the l ke fall t th g p t tem In pecti n or w k g E g a also f q ntly i lud d i th gen ral t rm tool

J st st d d p ts b mbl d int a n mbe f pe f end odu t so ge eral pu pose m ry d qu pment can be m d to do a peci l jol e per t by f tting it with the pr per tool r ac e ry eq ipment (s e JIG FIX TURE A D DIE DE IGN)

Selection of equipment T a gr t e t nt the elect n of eq pment i di tated l y the pr duc ti n meth d A degree f lat tud nearly always a ailal l within a gi en pr lu ti n method

Mu h equipm nt especially that n t directly u ed in form g or a embl ng ; rati n m y l e mm n t many pro l cti n m th d In selecting th eq i p ment on lerati n mu t l e gi n t the f ll wing fact r

1 D mand f r the pr duct hort or long term
2 P rman n f the prod ct I it lik ly to re ma n th ame or will tecl nological cha ge f r e maj r h nge in it d g ?
3 Ri k f equ pment l lescence
4 Competiti e ad antage l ad antage es tabl hed by h ice of qu pment
5 Integratio with ther a ailal le r on hand qu pment
6 Suitabil ty f eq ipment in relation to the product
7 Effect n qu lity f the pro luct
8 Q ial ty and a ailability of labor to operate eq pment
9 Co t f perating and m inta ni g the equ p ment
10 Co t urce and a ailal il t f capital

T resol the fi t fi e fa t s r q ir s p ni n or estimat s Deci i ns f r th s co d fi e can be ob t ned by evalu ting fact

A piece of equ pment may be s le ted from ta da d a il ble implements or may be b ilt pe ally f r th j b To decide f pec ally bu lt apparat s is appr pri te additi l fact r mu t be e alu te l

1 The ate at whi h the pr du t i t be made
2 The ol m r q ant ty of the p od ct to be man f tu ed
3 Th m n hour equ r d
4 Th fl p e a ail ble f the equipme t
5 The adapt b l ty of t d rd machines
6 The t a d d pr c ti charges of the pe ial equ pm nt ompa ed with st nd d equ p ment

T arr t a sound dec i n in the el tio of q pm t all ph of p od cti n u de pre r t d i ns and ant pated fut re ond tion must be fully tud d nd anal zed by pe ple x p en ed n the fi ld o e d by th v rio s f t

P d ti n eq ipm nt clas ed a neral pu po d r q the exte s finan ial rev ew th t mu t b g v n t pe al equ pment The mo t d ffic lt f ctor that m st be dete m ned fo the fina ial appr al f spe al equ pment is that f pr duct l fe related to th tim e y to re er th pit l n e t d i the quipm t.

I the final a aly is th bje ti e wh ch must be al ed in elect p odu tion equipme t to

engineering strives to use advance technology wherever it provides an economic advantage See INDUSTRIAL ENGINEERING JIG FIXTURE AND DIE DESIGN PILOT PRODUCTION PRODUCT DESIGN PRODUCTION METHODS [R I F]

Production methods

Basically all production processes and methods can be classified as one of two types Analytic industrial processes break down a given material into several products as in an ore reducing plant Synthetic processes create one product from several different materials as in a blast furnace or an automobile assembly plant Processes may be a combination analytic synthetic (wood furniture factory) or synthetic analytic (feed mill)

Industry frequently classifies proces es into those that (1) change the shape called forming including cutting molding bending dis olving machining (2) change the chemical or internal characteristics called treating including mixing blending heat treating refining (3) change the external surface called finishing including rinsing coating drying painting and (4) add other pieces called assembling including attaching joining packaging fitting and fastening as in erecting a new building or pinning a dress pattern to a piece of cloth

Mo t industries u e a combination of at least two basic processes In fact some processes can be placed logically in more than one class for example metal plating

Processes have also been classified into continuous or proces type operations as in an oil refinery and intermittent (or repetitive) or manufacturing type operations

Almost all production processes or methods change the form or condition of ome material or add or deduct other materials aided by men and/or machinery with the end objective being a product which has greater utility by nature of its form or characteristics than the initial material

The end product and the tart material are of fundamental importance Together these are termed the product material factor this factor is the chief influencing feature in the choice of production methods A change in the end product or in the characteristics of the start material may cau e or allow significant changes in the production proces es or methods

Design and specifications Design is inherent in the production of any product even if it is not formally recognized and recorded in prints photos or other specifications But generally product designs are establi hed prior to production and are frequently the result of e eral years of research experiment, and development

De ign of products generally calls for specialists of various kinds scientific engineering tylist or artistic market re earch or public relations and production engineers or manufacturing planners The more the e speciali ts (together with the sales purchasing production and financial departments) can integrate their views and ideas the more effective will be the product s design for the overall company position

Product de igns may take several forms formulae in chemical plants blends in food products and performance standards or drawings and specifications in manufacturing plants (see PRODUCT DESIGN)

The term production design is frequently referred to today as that design which has been engineered for ease and economy of production It is much more than a design which merely requires functioning of the product it involves refinements and modification of functional design ba ed on the processes production equipment and per onnel planned to produce the item

The design engineer specifies what is to be made and how well it is to be made The specifications take the form of (1) parts or materials li ts describing the elements (2) required characteri tics or dimensions (3) drawings photos blueprints or models and (4) performance of finished product or test specifications These are aimed at o describing the product and its elements that the equipment to produce it can be readily planned the purcha ed materials can be correctly obtained and the components can be made and a embled according to how the product has been engineered

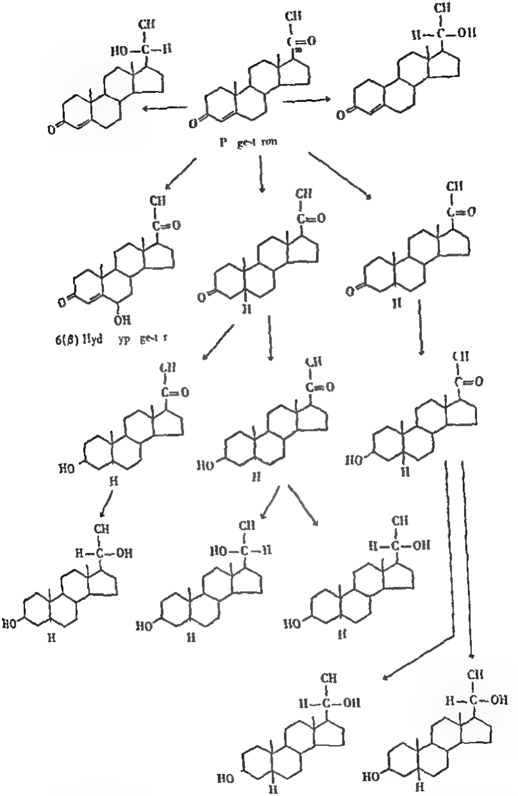
Other specifications pertain to the manufacturing process and the methods Process specifications are set by process engineers (as distinguished from product engineers) and cover just how proces es are to be controlled Methods instruction is generally set by methods engineers and covers how work area and machinery are to be arranged

Product specifications usually include tolerances because nothing can be made exactly A t lerance is a permissible variation (see PRODUCTION ENGINEERING)

Standard materials and parts While most products require different components and even the same products require many variations ranges and preferred choices of product dimensions or other characteri tics can be establi hed Whenever materials and parts can be graded classified or otherwise tandardized great savings in time and co t result for de igners purchasers producers and users

For example standard electrical current horsepower and dimen ion for electric motors allow the engineer to detail his overall machine readily the buyer to specify and buy by numbers and c de the producer to tool up for substantial quantities of standard sizes and the u er of the machine to obtain a replacement quickly should the original motor burn out

Standards have been establi hed for practically all materials from lubricating oil to paper from lumber to metallurgical pecifications of sand a t ing Standard gages of sheet metal sizes of crews and nuts and diameters of bearings are example of tandard parts we take for granted every day The e tandards are set by industry a ciations



F g 3(α) 0(α) 1 l

C t b l m f p g t l es ed t e t tr t on n th u n ı of h cal mpo ta c t t a bo t m 3 4 5 d 20 w ll ı d t o ı l ı g me tr l r g l rit hyd l t n b t m 6 (ıll trat d) d l n abn m l p gnanc e Se ANDROGE P g a e-3( ) 20( ) d l q t t t el th ESTROGEN STE OID ST ROL. m l mpo ta t m t b lit n h ma d t de

[R I D]

bring about a fair return on the money invested in that equipment This criteria alone motivated the individuals who have foregone the opportunity of spending this money in other way so as to provide funds for the purcha e of production equipment

Supporting services In addition to the machinery equipment and tools used for production every factory plant or mill must have certain supporting services These take various forms

Services dealing with materials or product include (1) production control such as planning scheduling machine loading dispatching and recording (2) material control including requisitioning receiving storing tran porting inventorying (3) quality control which includes quality levels inspection complaints specifications release (4) waste control dealing with rejects salvage scrap or rework and (5) warehousing and shipping

Services relating to machinery and equipment include (1) maintenance both preventive and repairs and overhaul (2) tool storage and tool conditioning (3) auxiliary or utility lines such as water electricity heating and ventilating compressed air or vacuum lubricating or cutting oil gas exhaust fuel drains ewage and the like

Services relating to personnel include (1) offices (2) restrooms lockers showers (3) eating facilities (4) parking lots and access ways (5) time clocks drinking fountains first aid bulletin boards telephones and so on

Most supporting services are necessary for a modern production facility They must be planned into the facility and integrated with the materials machinery men and the building structure Effective arrangements and organization of these supporting facilities often account for the efficiency of the production methods established As a result they should not be overlooked when new or revi ed production methods are being planned (*see* PLANT FACILITIES) [R M]

Production planning

Two objectives of the manufacturing division of a business are to produce the company s products promptly and profitably To attain these objecti es requires efficient use of manpower machines and materials This in turn requires coordinating the activities of each di ision of the company This is done by determining the required and the available capacities and preparing a plan for matching them

In many companies the planning is ass gned to a production planning department who e personnel also follow progress and adjust the plans to compen ate for the differences between planned and actual performance Much of this department s work is gathering processing distributing and storing information

Planning production from start to finish includes scheduling the progress of new products foreca t ing demand keeping records of available quantities of material preparing schedules reconciling cu tomers demands inventory balances and pro-

ducti loadin fee h riod tween p rent p r formall panie

Comp achieving by th pr pen es and

One ing how mu and having panie use terval requir and the final chedules are Other compan found to be af uct *See* GANTT

Bibliography and *Inventory C Control Text and*

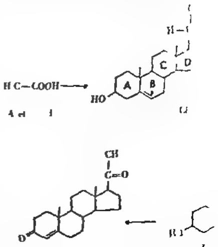
Progesterone

A steroid hormone and placenta The h iological role in the h cycle and in the ma dition to these function the testis and adrenal intermediate in the b trogens and the corti oids)

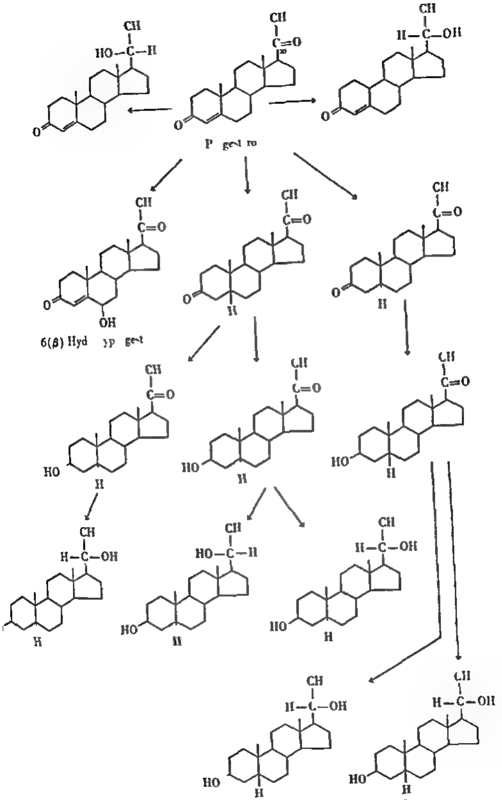
The biosynthetic pat common to all of the te involves

Acetate → Cholesterol → Pregnen

The blood contains in the 20(α) and 20(β) red have reduced biological acti



Progesterone



tabol m of p g te s les d t t m t n th re f l al mp t nc
at b at m 3 4 5 a d 20 a well o d t ns l me t al g l t es
x l t b n t m 6 (a ll t t d) d l o n b m l pr gn S ANDROGEN
g n 3( ) 20(α)-d l q t t t ly th E T OGEN STE O D STEROL
t mporta t m tabol t h m d tt de [R I D]

bring about a fair return on the money invested in that equipment. This criteria alone motivated the individuals who have foregone the opportunity of spending this money in other ways so as to provide funds for the purchase of production equipment.

Supporting services. In addition to the machinery, equipment, and tools used for production, every factory, plant, or mill must have certain supporting services. These take various forms.

Services dealing with materials or product include (1) production control, such as planning, scheduling, machine loading, dispatching, and recording; (2) material control, including requisitioning, receiving, storing, transporting, inventorying; (3) quality control, which includes quality levels, inspection, complaints, specifications release; (4) waste control, dealing with rejects, salvage, scrap, or rework; and (5) warehousing and shipping.

Services relating to machinery and equipment include (1) maintenance, both preventive and repairs and overhaul; (2) tool storage and tool conditioning; (3) auxiliary or utility lines, such as water, electricity, heating and ventilating, compressed air or vacuum, lubricating or cutting oil, gas, exhaust, fuel, drains, sewage, and the like.

Services relating to personnel include (1) offices; (2) restrooms, lockers, showers; (3) eating facilities; (4) parking lots and access ways; (5) time clocks, drinking fountains, first aid, bulletin boards, telephones, and so on.

Most supporting services are necessary for a modern production facility. They must be planned into the facility and integrated with the materials, machinery, men, and the building structure. Effective arrangements and organization of these supporting facilities often account for the efficiency of the production methods established. As a result they should not be overlooked when new or revised production methods are being planned (*see* PLANT FACILITIES). [R.M.]

Production planning

Two objectives of the manufacturing division of a business are to produce the company's products promptly and profitably. To attain these objectives requires efficient use of manpower, machines, and materials. This in turn requires coordinating the activities of each division of the company. This is done by determining the required and the available capacities and preparing a plan for matching them.

In many companies the planning is assigned to a production planning department, whose personnel also follow progress and adjust the plans to compensate for the difference between planned and actual performance. Much of this department's work is gathering, processing, distributing, and storing information.

Planning production from start to finish includes scheduling the progress of new products, forecasting demand, keeping records of available quantities of material, preparing schedules, reconciling customers' demands, inventory balances, and production capacities, issuing realistic schedules, loading machines, dispatching, expediting, and feeding back or adjusting the next production period's schedule to compensate for the difference between planned and actual performance in the current period. Someone does each part of this work formally or informally in most manufacturing companies.

Company objectives may shift rapidly from achieving maximum output to shipping each order by the promised date to minimizing operating expenses and the inventory investment.

One essential in production planning is knowing how much time to allow between starting work and having a product ready to deliver. Some companies use a master schedule which shows the interval required between the first purchase order and the final shipment of the product. Master schedules are useful but difficult to keep up to date. Other companies prefer to use lead times they have found to be safe for each material, part, and product. *See* GANTT CHART; INDUSTRIAL CONTROL. [L.F.S.]

Bibliography: J. F. Magee, *Production Planning and Inventory Control*, 1958; W. Voris, *Production Control: Text and Cases*, 1956.

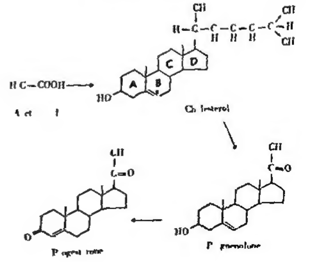
Progesterone

A steroid hormone produced in the corpus luteum and placenta. The hormone has an important physiological role in the luteal phase of the menstrual cycle and in the maintenance of pregnancy. In addition to these functions, progesterone produced in the testis and adrenals occupies a key role as an intermediate in the biosynthesis of androgens, estrogens, and the corticoids (adrenal cortex steroids).

The biosynthetic pathway to progesterone is common to all of the steroid-producing tissues and involves

Acetate → Cholesterol → Pregnenolone → Progesterone

The blood contains, in addition to progesterone, *the 20(α) and 20(β) reduced metabolites*, which have reduced biological activity.



$\Delta F(n)$ $F(+1) - F(n)$ and perfo ming tl e d c ted ummat

E mple 1 The ar thmet c progres ion (1)

$$\sum + b(n-1) = (a-b)n + \tfrac{1}{2}b^{(2)}\Big|^{N+1}$$

$$= (- b) N + \tfrac{1}{2}b(N+1) N$$

E ample 2 Th ge metri progre i n (2)

$$\sum_{1}^{N} = \frac{a}{-1}\Big|_{1}^{N+1} = \frac{r^{N}-1}{r-1}$$

Ex mple 3 The c ne equence

$$\sum_{n=}^{N} c \quad \alpha = \frac{n\,(n-\tfrac{1}{2})\alpha}{2 s n \tfrac{1}{2}\alpha}\Big|_{1}^{N+}$$

$$= \frac{(N+\tfrac{1}{2})\alpha - n\tfrac{1}{2}\alpha}{s \ \tfrac{1}{2}\alpha}$$

I der to m p ly m l $P( )$ of degr e k $P( )$ may be pre d in t rm of f ctorial p w er n) n) ^{k} by Newt n the r m

$$P( ) \quad P(0) + \frac{\Delta P(0)}{1!} ( ) + \frac{\Delta P(0)}{} (2)$$

$$+ \qquad + \frac{\Delta P(0)}{k!} n^{(k}$$

The d ff f $F( )$ wh $n = 0$ r mputed a T bl 3

T bl 2. A t d ff en es

$f( )$	$\Delta\ f( )$
0	co t
	$\overline{-1}$ ($\neq 1$)
	$\overline{k+1}$ ($k \neq -1$)
l	(k 0)
co $n\alpha$	$\frac{(\ \tfrac{1}{2})}{2\ \tfrac{1}{2}}$
$n\alpha$	$-\frac{\cos(\ \tfrac{1}{2})\alpha}{2\ \tfrac{1}{2}}$

T bl 3 Seq n of c bes

	0	1		3	
$F( )$	0	1	8	7	$F(0) = 0$
$\Delta P( )$	1	7	19		$\Delta F(0) = 1$
$\Delta F( )$	6	1			$\Delta F(0)/\ 1 = 3$
$\Delta P( )$	6				$\Delta F(0)/3! = 1$

In Table 3 $P(n) = n$ and l ence

$$n^{3} = n^{(1)} + 3^{\ (2} + \ ^{(3)}$$

$$\sum_{n=1}^{N} n^{3} = \tfrac{1}{2}n^{(2)} + \ ^{(3)} + \tfrac{1}{4}n^{( )}\Big|_{1}^{N+1}$$

$$= \tfrac{1}{4}n^{2}(n-1)^{2}\Big|_{1}^{+1} = \tfrac{1}{4}(N+1) N^{2}$$

Summati by parts

$$\Delta^{\ 1}[f( )\,\Delta g( )] = f( )g(n) - \Delta^{-1}[g(+1)\,\Delta f(n)]$$

is fr quently eful in f d g a ti l ff rences With $g( ) = (-1)$ $\Delta g( ) =$ $(-1)^{-1}$ th g s

$$2\Delta^{-1}[(-1)^{\ -}f( )]$$
$$= (-1) f( ) - \Delta^{-1}[(-1)^{\ -1}\Delta f(n)]$$

When $P( )$ s a polyn m l f d g e k Δ $^{1}P(n) = 0$ nd this f mul e pe tedly appl ed w ll g v

$$\Delta^{-} [(-1) \quad P( )]$$

nd l nc tl e um $\sum_{=1}^{N} (-1)^{\ -1}P( )$ Th f ll w ng t bl perm t the mmat n of alt rn t n pow rs $(-1)^{\ -1\ k}$

k	$\Delta^{-} [(-1)^{\ -1}n\ ]$
1	$\tfrac{1}{2}(-1)\ (n-\ \tfrac{1}{2})$
2	$\tfrac{1}{2}(-1)\ n(\ -1)$
3	$\tfrac{1}{2}(-1)\ (n-\tfrac{1}{2})(n^{2} - \ -\tfrac{1}{2})$
4	$\tfrac{1}{2}(-1)\ n(\ -1)(n^{2} - \ -1)$
5	$\tfrac{1}{2}(-1)\ (n-\tfrac{1}{2})(n - \ -1)^{2}$

S mm ti n by part also give antid ff e s u h a Δ [$P( )$] Th Δ $(n\ ) =$ $p(n-p)$ whe e $p =$ $/(-1)$ See SERIES [L BR]

B bl og phy L M M l Th mp n *The C l c lus f F it D ff* s 1933

Progression (mathematics)

Ordered countable sets of numbers x_1 x x_3 not necessarily all different In general such sets are called equence whereas the term pro gre sion is usually confined to the special types the arithmetic in which the difference $x_k - x_{k\ 1}$ between succe sive terms is constant the geomet ric in which the ratio $x_k / x_{k\ 1}$ is constant and the harmonic in which the reciprocals of the terms are in arithmetic progression

Arithmetic progressions If the first term is a and the common difference b

$$x_1 = a \quad x \quad = a + b \quad x_3 = a + 2b$$
$$x \quad = a + (n - 1)b \tag{1}$$

In the sum of n terms S two term equidi tant from the ends always have the same sum $x_1 + x$ hence $2S \quad = n(x_1 + x \ )$ and

$$S \quad = n\frac{x_1 + x}{2} = n\left(a + \frac{n-1}{2}b\right)$$

If x_1 x x_3 are in arithmetic progression $x =$ $(x_1 + x_3)/2$ is called the arithmetic mean of x and x_3

Geometric progressions If the fir t term is a the common ratio r

$$x_1 = a \quad x \quad = ar \quad x_3 = ar$$
$$x \quad = ar^{\quad 1} \tag{2}$$

Excluding the case $r = 1$ (when all terms are the same) the sum S of n terms satisfies $S \quad - rS \quad =$ $a - ar$ hence

$$S \quad = a\frac{1 - r}{1 - r}$$

If $|r| < 1$ $r \rightarrow 0$ as $n \rightarrow \infty$ hence the sum of the infinite geometric series

$$\sum_{=1}^{\infty} ar^{\ -1} = \frac{a}{1 - r} \qquad |r| < 1$$

If x_1 x x are in geometric progres ion $x =$ $\sqrt{x_1 x_3}$ is called the geometric mean of x and x Since

$$(\sqrt{x_1} - \sqrt{x_3})^2 = x_1 + x_3 - 2\sqrt{x_1 x_3} \geqq 0$$

and
$$\frac{x_1 + x_3}{2} \geqq \sqrt{x_1 x_3}$$

the arithmetic mean of two unequal po iti e num bers exceeds their ge metric mean

The arithmetic mean A and tl ge metric mean G of n po iti e numbers are defined a

$$A = \frac{x_1 + x + \quad + x}{n} \quad \text{and} \quad G = \sqrt{x_1 x_2 \quad x}$$

also $A \geqq G$

Harmonic progression The reciprocal of the equence (1) form a harmonic prc gre ion Tl ere i no compact expres ion for the um of n term

If x_1 x x_3 are in harmonic progre ion

$$x \quad = \frac{2x_1 x_3}{x_1 + x_3}$$

is called their harmonic mean

Sum sequence A general method of umming a equence of n term de end u on a theorem in the difference calculu which i the analo of the fundamental theorem of the differential calculu

If $x \quad = f(n)$ is defined for $n = 0\ 1\ 2$ tl e difference $f(n)$ i defined as

$$\Delta f(n) = f(n + 1) - f(n)$$

Δ is a linear operator that i

$$\Delta[af(n) + bg(n)] = a\,\Delta f(n) + b\,\Delta g(n)$$

In the difference calculus the factorial powers $n^{(k)}$ for integral k are defined by

$$n^{(k)} = \begin{cases} n!/(n - k)! & k < n \\ n! & k = n \\ 0 & k > n \end{cases}$$

Thus

$$n^{(k)} = n(n - 1)(n - 2) \qquad (n - k + 1) \quad 0 < k \leq n$$
$$n^{(-k)} = \frac{1}{(n + 1)(n + 2) \qquad (n + k)} \qquad k > 0$$

In particular

$$n^{(\ )} = 1 \quad n^{(\ )} = n \quad n^{(\quad)} = 1 \quad (n + 1)$$

Moreover $n^{(k}$ ati fie the functional equation

$$n^{(k)} \quad (n - k)^{(h)} = n^{(h)} \quad (n - h)^{(k)} = n^{(h+k)}$$

The last two entries of Table 1 fc llow from

$$\Delta e \quad = (e \quad - 1)e \quad = ^{?} \text{ in } ^{1} \alpha \ ^{(\quad 1\ 2)}$$

on takin real and imaginary part

If $\Delta F(n) = f(n)$ $F(n)$ i alled the antidiffer ence of $f(n)$ and written Δ $f(n)$ T ant differ ences of $f(n)$ differ at mo t l y a on tant (r ly a peri dic functi n of eri d 1 f r functi n $f(x)$ of a continuou arial le) Tal le 1 implie tl e table of antidifferen e (Tal le ?)

Ju t as antiderivative are i ed to compute defi nite integral antidifference are u d to c mpute def nite m

$$\sum f(n) = \Delta^{-1} f(n) \quad ^{+1} = F(q + 1) - F(p)$$

The proof is immediate on replacing $f(n)$ l y

Table 1 D ffe ences

$f(\ )$	$\Delta f(\ )$
co 1 t	0
	$(\ - 1)$
)	k
cos α	$-$ ½α (+½)α
α	½α c (+½)α